Development and initial trials of a new multiphase well testing tool for coalbed methane evaluation

by

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INTRODUCTION

The Commonwealth Scientific and Industrial Research Organisation (CSIRO) is developing a multiphase well testing tool to measure key factors that control the production of methane gas and water from coal seams. The most important controlling factors include intrinsic permeability, relative permeability to water and to gas, static reservoir pressure, and gas desorption pressure. The tool under development can collect data representing water and gas pressure, water and gas flow rate, and temperature. A computer simulator incorporating the various mechanisms of methane production can interpret the well test responses to characterise the coal seam and forecast its gas and water production potential.

The multiphase tool operates in and HQ size borehole. A pair of inflatable packers isolates an interval containing the target coal seam. A pneumatically operated, positive-displacement pump withdraws water at a constant rate from the test interval. Pressure transducers measure the response to pumping in the test interval itself as well as in the borehole both above and below the test interval. A metering system at the surface separates the gas and water and measures the flow rates individually. A data recording system receives and records signals from downhole pressure and temperature sensors via a wireline cable and from surface flow rate and temperature sensors.

A prototype system gathered data at three locations from a coal seam in the Bowen Basin of Queensland. The pressure response to pumping proved to be sufficient to determine intrinsic permeability, static reservoir pressure, and gas desorption pressure of the coal. Successful use of the prototype tool has encouraged further development to measure all of the critical factors such as relative permeability and desorption isotherm parameters.

THEORY

Permeability is obviously one of the most important factors controlling the production of water and methane gas from a coal seam. Relative permeability is of even greater significance in simulating the behaviour of coal seam reservoirs [Jones *et al.*, 1988; Arastoopur and Chen, 1991]. The literature about gas and water permeability in coal is limited, however, at best. The CSIRO has undertaken both laboratory and field programs to improve the quantity and quality of information about relative permeability of coal.

The objective of the field program is to develop a well testing tool that can measure water pressure, gas pressure, water flow rate, gas flow rate, and temperature in time. A specific model describing the mechanisms of coalbed methane production can interpret these data to characterise the gas production potential of a coal seam. The results of such data interpretation include values for intrinsic permeability of the coal seam, relative permeability to gas and water, static reservoir pressure, and gas desorption pressure. The illustration in Figure 1 depicts the concept underlying methane production. Many coalbed methane reservoirs are saturated with water under hydrostatic pressure at equilibrium conditions. The methane gas adheres to the surfaces of the porous coal matrix and natural cleat system by an adsorption mechanism. Hydrostatic pressure acts to hold the adsorbed methane gas in place. Pumping in a well completed in the coal seam reduces the pressure and initiates single-phase flow of water (Stage 1 - Saturated flow regime). Continued water production further reduces the pressure in the coal until methane begins to desorb from the surfaces of the coal matrix forming gas bubbles in the pores and cleats of the coal (Stage 2 - Unsaturated flow regime). In Stage 2, gas partially saturates the coal, but the gas is not flowing. The gas bubbles in the coal obstruct some of the pathways available for water flow and decrease the relative permeability to water. This reduced relative permeability to water increases the pressure drawdown in the well, observed as increasing slope of pressure change versus time. Two-phase flow (Stage 3 - Two-phase flow regime) finally starts as the reservoir pressure continues to decrease with pumping and additional gas desorbs from the coal. The gas saturation increases until gas bubbles connect to form continuous pathways to the wellbore and gas starts to flow. The relative permeability to gas becomes non-zero when two-phase flow starts. Further reduction of the reservoir pressure extends this sequence of changing flow regimes outward over time from the wellbore into the coal seam.

Investigations sponsored by the Gas Research Institute of Chicago give an example of the behaviour seen in the three flow regimes described above. Figure 2 shows the response during a constant-rate injection test following a hydraulic fracture stimulation treatment in a well at the Rock Creek coalbed methane experimental site in the Warrior Basin of Alabama. The dashed line in Figure 2 shows the trace of the single-phase response during an injection test before the well started normal production. The drawdown response during production follows along the injection response until about the fourth day. Then the drawdown accelerates probably because gas desorption starts at the onset of unsaturated flow. Methane gas appeared at the wellhead after about 50 days. The pressure behaviour in all three stages, or flow regimes, appears in production data from this well. Koenig *et al.* (1989) discuss these topics more thoroughly.

Conventional analysis techniques are suitable to determine the intrinsic permeability and reservoir pressure during the single-phase flow of water in the coal seam. Koenig *et al.* (1989) have described a method suitable to analyse pressure data to obtain values for relative permeability, gas desorption pressure, capillary pressure, and desorption isotherm parameters. History-matching of test data with existing computer models that describe desorption of methane and two-phase flow in coal seams, SIMED from the University of New South Wales or COMET-PC for example, can yield values for these parameters.

TOOL DESCRIPTION

A schematic diagram of the prototype two-phase tool appears in Figure 3. The tool fits in an HQ size (96 mm diameter) borehole to test intervals at depths up to 300 metres (Figure 4). Two inflatable packers isolate the target coal seam. Drill rods (BQ size) of various lengths serve to adjust the distance between the packers to suit the thickness of the coal seam. High pressure compressed air or nitrogen inflates the upper and lower packers to form a seal against the sides of the borehole isolating the test interval from the rest of the borehole. A pneumatically powered pump mounted in a stainless steel chamber above the upper packer withdraws water at a constant rate from the isolated test interval (Figure 5). A hydraulically powered air compressor supplies pneumatic pressure to control the pump at a rate appropriate for the conditions of the coal seam. A pressure transducer mounted in a stainless steel chamber above the upper packer monitors the pressure in the borehole above the test interval to check that there is no communication between the test interval and the upper portion of the borehole. Two pressure transducers (Figure 6) mounted in another stainless steel chamber below the lower packer monitor the pressure in two locations: (1) the test interval between the packers (the zone of interest) and (2) the borehole below the test interval. The downhole pressure transducer checks to make sure that there is no communication between the test interval and the lower portion of the borehole.

A sensor mounted near the top of the lower packer measures the temperature in the test interval. Temperature is an important factor that influences gas flow rates and water viscosity downhole.

A tubing bundle connects the air compressor at the surface with the pump down hole. The tubing bundle contains an air inlet line and an air exhaust line to power the pump. The tubing bundle also has a pump discharge line to conduct produced water and gas to the surface separating and metering facility. A high pressure hose to inflate the packers connects them to a cylinder of compressed air or nitrogen at the surface. A cable reel at the surface feeds a signal cable for the pressure transducer outputs along with the tubing bundle and the high pressure hose for tripping into the hole. A port in the pump chamber gives access to service a filter at the pump inlet. The filter protects the pump from solid particles in the wellbore fluid that could cause the pump valves to malfunction. A computer controlled data acquisition system at the surface receives and records signals from the pressure transducers, temperature sensors and flow meters. Commercial computer software provides a continuous display of the real-time data to keep the test operator fully informed throughout the test.

An important feature of the tool is its ability to discharge gas and water simultaneously. The onset of gas production does not prevent the pump from continued water production. The small volume of the isolated test interval containing the coal seam practically eliminates wellbore storage effects. These features allow the operator to observe all three stages of production in a reasonably short time. Consequently, the multiphase well testing tool becomes a useful exploration device.

OPERATIONAL PROCEDURES

An electrically powered reel handles the tubing bundle for lowering or raising the tool in the borehole (Figure 7). From separate reels, the operator tapes the signal cable and high pressure hose to the tubing bundle while lowering it into position across the target coal seam. With the tool in place and all systems connected, the data acquisition system monitors the pressure transducers and temperature sensors until the readings stabilise. A brief period of operating the pump while returning the discharge to the wellbore allows adjusting the water discharge rate to a predetermined value suitable for the particular test interval. Packers inflated to about 2 MPa above the hydrostatic pressure assure a secure seating of the packers and isolation of the test interval. Another period of monitoring the sensors during equilibration to static conditions follows packer inflation. After starting the pump, the data acquisition system records test data as the downhole pressure declines in the test interval and the production of gas eventually starts. The operator can decide when to stop the pump based on the data displayed during the pumping period. The pressure in the test interval usually reaches a minimum value during vigorous gas production. Monitoring of the pressure buildup in the shut-in test interval after the pump has stopped may provide information potentially suitable for additional interpretation. Gas and water samples collected at the surface are available for chemical analyses to supplement the data set.

FIELD TRIALS OF THE TOOL

The prototype two-phase well testing tool has successfully measured the permeability, static reservoir pressure, and gas desorption pressure of a coal seam in the Bowen Basin of Queensland. The target seam currently is mined commercially. The test sites were located in virgin coal well ahead of mining operations. Field trials of the tool proceeded according to the operational procedures described above.

The pressure responses to pumping at a constant rate from the isolated coal seams in two wells 500 metres apart appear in Figures 8 and 9. In both cases, the initial response after the start of pumping followed a trend typical of single-phase flow of water. In other words, a plot of downhole pressure versus the logarithm of time is linear at first. Next there was a gentle acceleration of the pressure drawdown coinciding with the start of methane desorption and reduction of relative permeability to water. This transition to unsaturated flow appeared as a deviation from the initial straight line on the plot showing downhole pressure versus logarithm of time (Figure 10). Finally, drawdown continued to accelerate as the first evidence of gas production appeared in the discharge stream at the surface. There followed a steady increase in gas flow rate to a state of vigorous gas production. The downhole pressure reached a minimum value during this vigorous gas production and then started to increase as pumping continued. The pressure data were sufficient to compute the intrinsic permeability, static reservoir pressure, and gas desorption pressure. The full potential of the tool to yield data needed to compute relative permeability, capillary pressure, and desorption isotherm parameters was unrealised because the surface separation and metering facilities were unavailable at the time of the field trials.

The field trials revealed a number of mechanical and electrical problems requiring attention. Hydrostatic pressure in the well at depths below 100 metres crushed the pneumatic lines and discharge line to the pump hindering its efficient operation. Tubing with thicker walls made of stronger material solved that problem and should allow the pump to operate efficiently at depths up to 600 metres. The next generation of the multiphase tool will have an operating range of 600 metres. The electrical faults probably resulted from improper handling of the tool in the field and proved to be trivial in nature. A sturdier design for passing electrical lines through conduits and better handling of the tool in the field should remedy those problems.

The field trials of the multiphase tool have confirmed the underlying concepts of the tool's design. Investigation is in progress into proper means to interpret and apply the field data that the tool is capable of collecting. We expect that the finished multiphase tool will provide a new way to gather information that can significantly advance the understanding of water and gas flow in coal seams. We feel that the tool has the potential to provide information useful for coalbed methane exploration, design, and economics. There is an added benefit to the coal mining industry to investigate safety issues involving methane gas and to help engineer a safe mining environment.

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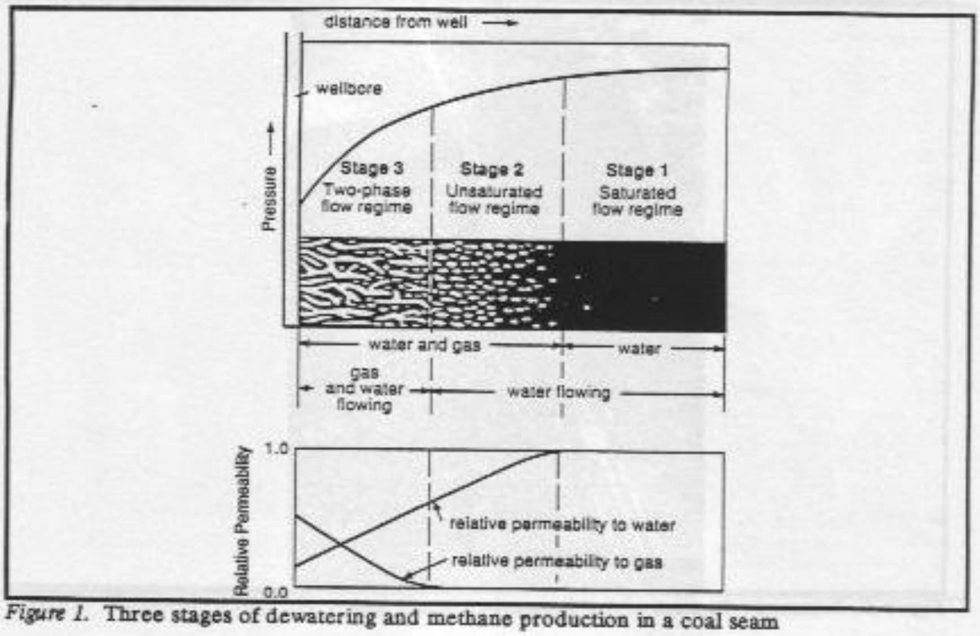

Figure 1. Three stages of dewatering and methane production in a coal seam

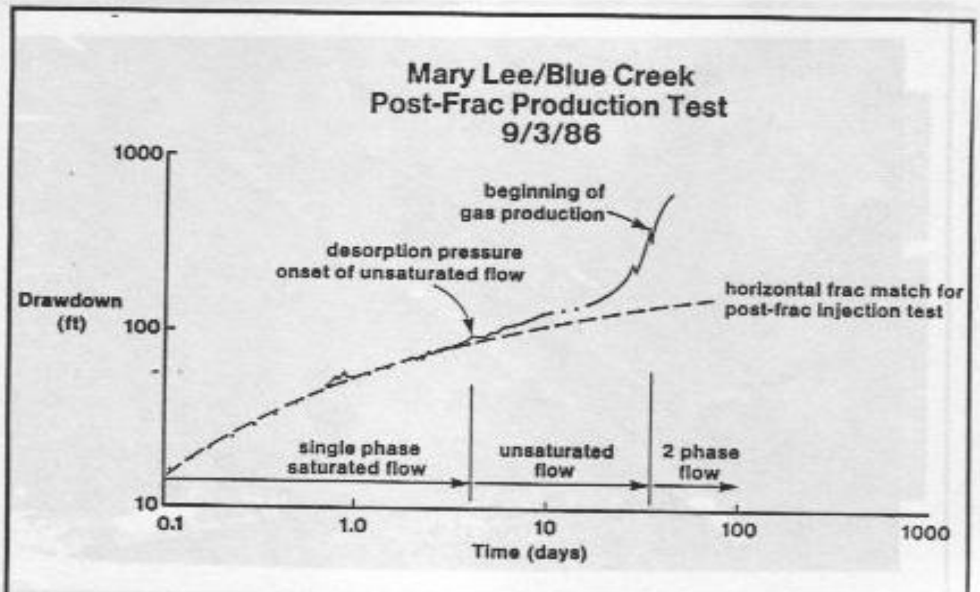

Figure 2. Comparison of Mary Lee/Blue Creek production to post-fracture injection test, well P1B.

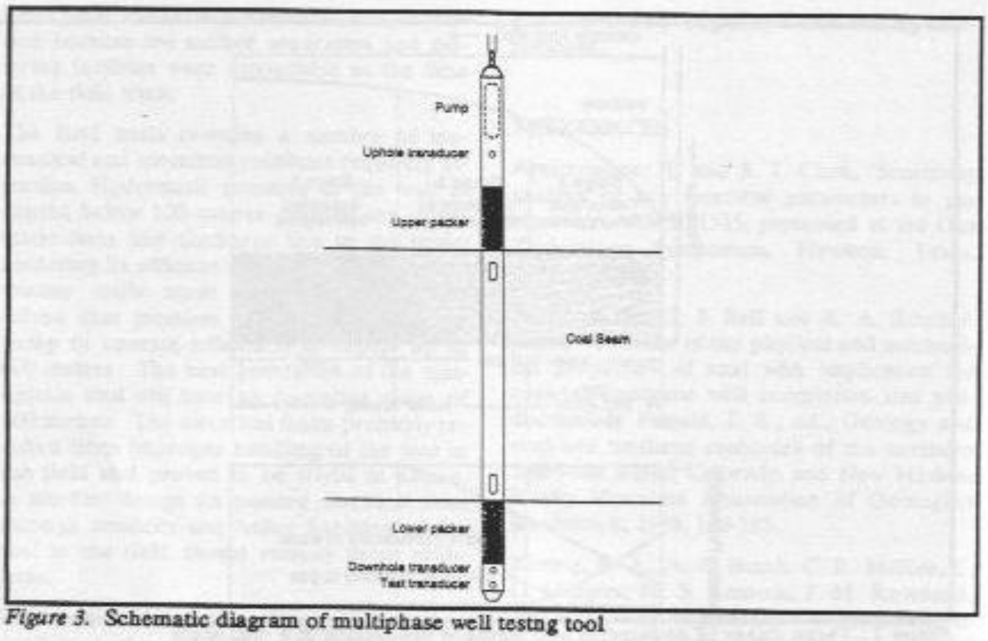

Figure 3. **Schematic diagram of multiphase well testng tool**

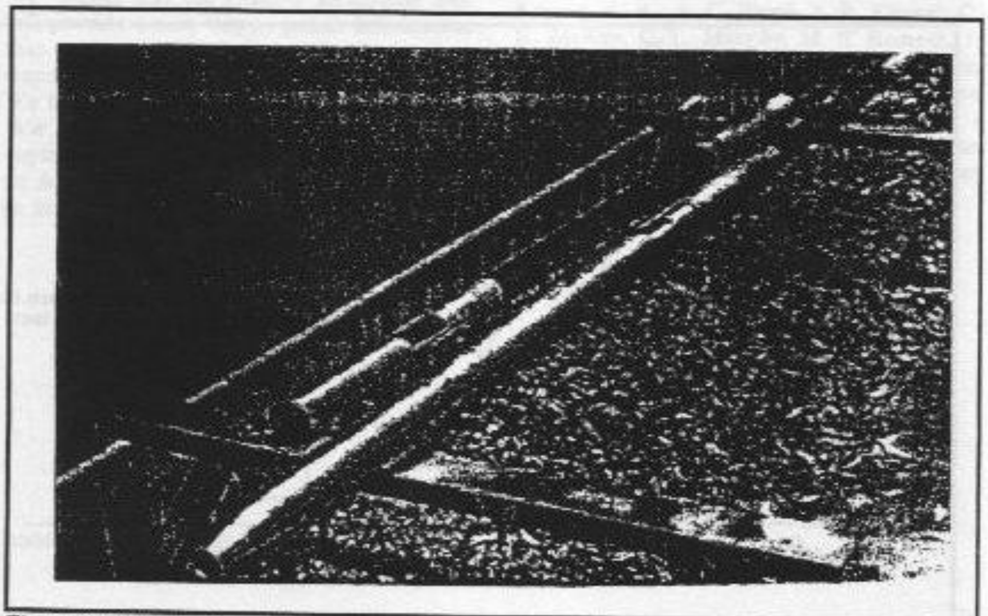

Figure 4. **Lower packer and transducer chamber (left). Upper packer and chamber for transducer and pump (right).**

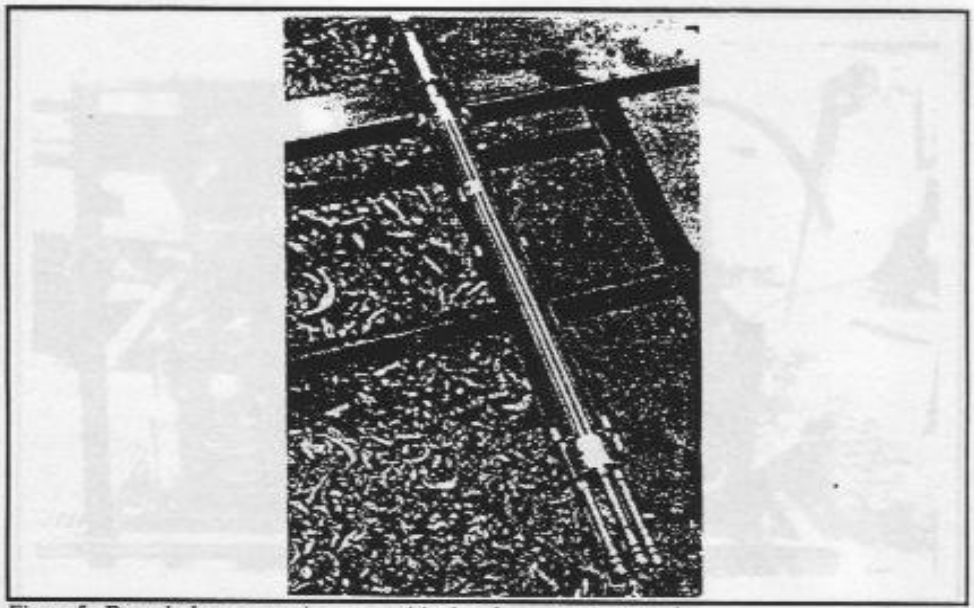

Figure 5. Downhole pneumatic pump with chamber cover removed

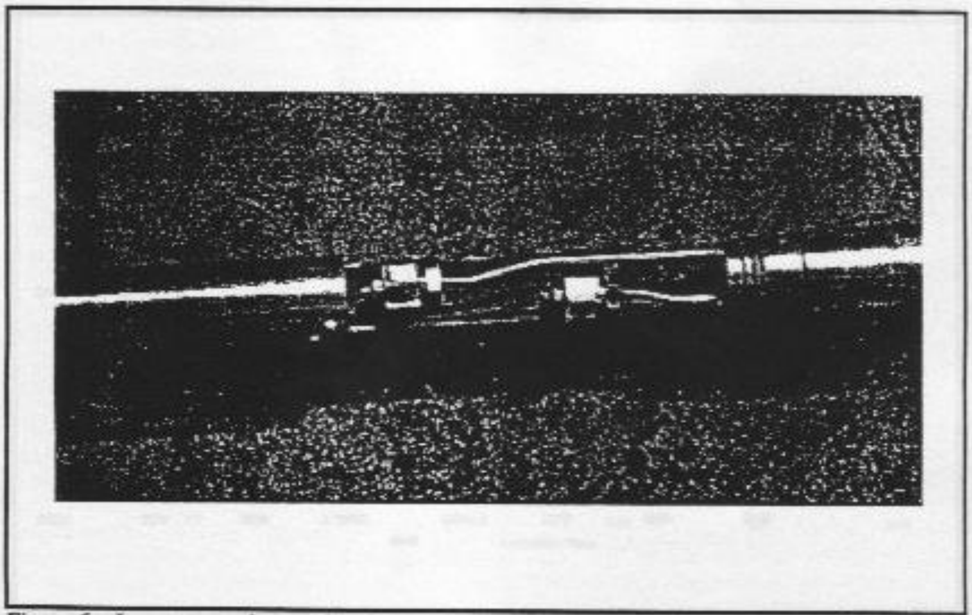

Figure 6. Lower transducer chamber with test transducer (left) and downhole transducer (right).

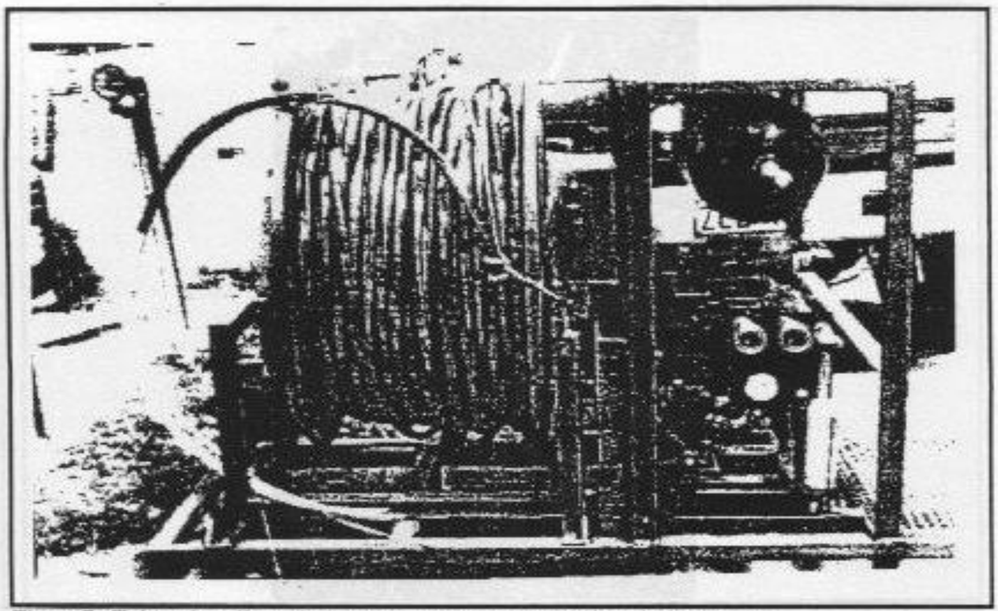

Figure 7. Tubing bundle and air compressor to operate downhole pump..

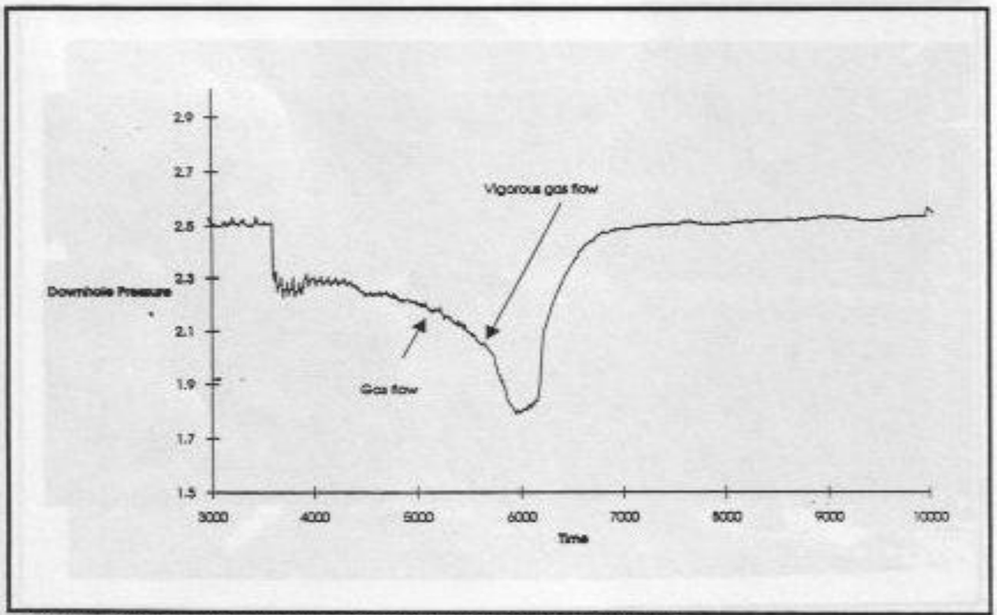

Figure 8. Pressure response to pumping at a constant rate, case 1.

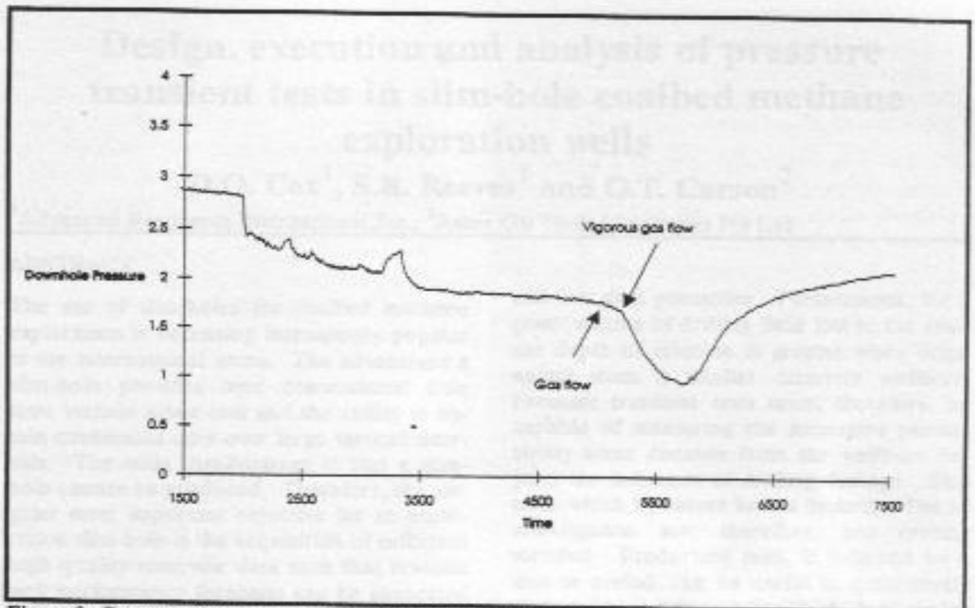

Figure 9. Pressure response to pumping at a constant rate, case 2.

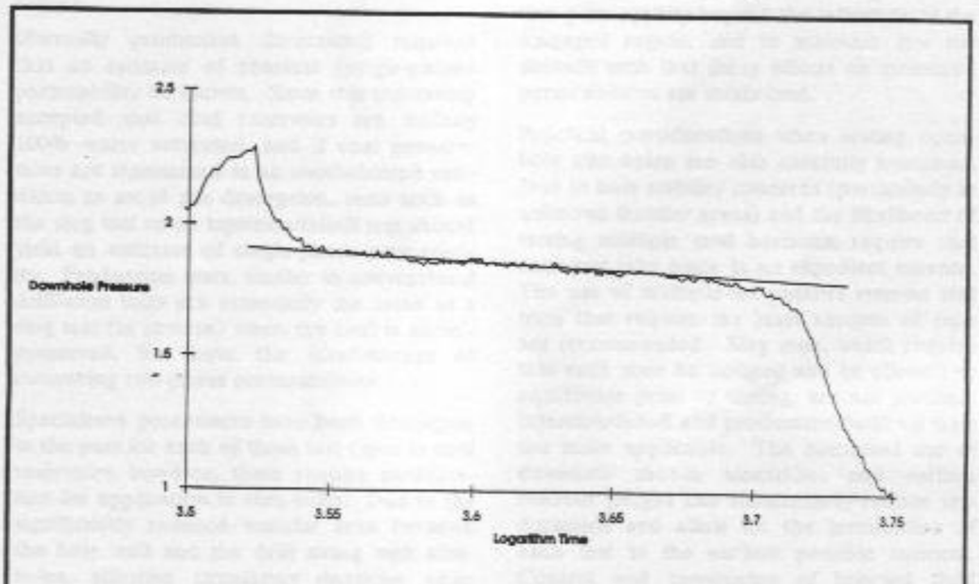

Figure 10. Downhole pressure versus logarithm of time, case 2.