COAL SEAM DEGASIFICATION BY USE OF HYDRAULIC FRACTURING IN VERTICAL WELLS
CASE HISTORIES

By
W.J. STEWART[1] and L. BARRO[2]

Abstract

Very large reserves of gas are contained in coal. Because of the low permeability of the coal gas flow rates are very low. Fracturing of the coal can be achieved by use of the nitrogen - foam frac techniques described but the flow rates after fracturing are not sufficient to support economic development.

Fracturing of the seams in the Bowen Basin was as predicted but in the Sydney Basin no trace of the fracture could be found when development proceeded past the fractured well.

Testing of coal samples has provided some insight into parameters affecting desorption rates.

Introduction

Reports in the literature on recent advances in formation fracturing techniques and their application in the coal mining industry led us to investigate the possible use of this method in Australia.

Hydraulic fracturing was a method developed in the petroleum industry in the 1950's for increasing the productivity of low permeability reservoirs. By injecting a suitable fluid at a pressure high enough to overcome in-situ rock stresses, a fracture is initiated near the well. After initial breakdown of the formation, the fracture grows as the volume of injected fluid is increased. By adding a propping agent, such as sand, to the stimulation fluid, the fracture is filled to prevent it closing when pumping ceases and the injected fluid is reproduced. It is necessary to use a proppant that will form a permeable flow channel in the reservoir and thereby link the well bore to reservoir fluids hundreds of feet away which would normally take a long time to be produced.

Gas is formed in coal seams during the coalification process and is mostly adsorbed on the internal surface of the porous coal with some trapped as free gas in the fracture or cleat system. This gas is usually more than 90% methane with lesser amounts of higher hydrocarbons, CO_2, N_2 O_2 H_2 and He. It generally has a heating value of approximately 1,000 BTU/cu.ft. which is comparable to commercial natural gas produced from petroleum reservoirs.

Coal itself has a very low permeability and it is thought that the gas is produced mainly through the system of butt cleats feeding into the more continuous face cleat system. A propped, hydraulically induced fracture could link a great number of these natural fractures directly to the wellbore and hopefully increase gas production sufficiently to make the project commercial. This technique has been successfully used in the U.S.A. for coal seam degasification (Elder & Deul., 1974).

---

1. Production Manager
2. Production Engineer
Oil and Gas Division
The Broken Hill Proprietary Company Limited
Melbourne.

While our main aim was to produce gas at commercially viable rates, it was recognised that production of the gas ahead of mining should be beneficial to the mining process.

Use of a foamed stimulation fluid had been developed for use in tight petroleum reservoirs in the U.S.A. The development of this fluid had been undertaken to eliminate the use of other fluids which had a damaging effect on the formation and also the foaming of the fluid allowed it to be reproduced much more rapidly as the foam would flow back naturally when the injection pressure was released and therefore stayed in contact with the formation for a much shorter time. The application of this foamed fluid to coal degasification was described by Steidl in 1978.

Location Selection

A study was made of areas held under coal mining lease by BHP at the same time making sure that potential areas were not within petroleum leases held by other parties. We determined that the leases at Blackwater, Queensland and Appin, N.S.W. offered potential for a test site and petroleum exploration titles were obtained over both areas.

Mines in both areas produce good quality coking coal and the coal/leases were estimated to contain gas reserves in the order of 210 x 10^6 m^3 at Blackwater and 6 x 10^6 m^3 at Appin. In the total area of the petroleum title in the Bowen Basin we estimate that gas reserves of 200 x 10^6 m^3 exist similar to the estimated reserves of the North West Shelf on which a large LNG project will be based.

Market potential existed in the Rockhampton/Gladstone area some 200/km to the east of Blackwater while a spur off the Moomba-Sydney gas line ran through the Appin lease and of course we had a large market for gas in our steel plants at Port Kembla.

Further to this, the Leichhardt colliery at Blackwater was experiencing considerable difficulty with mining due to coal bursts and production rates had been severley restricted. (The colliery has since been closed due mainly to the uneconomic production rate). Problems with high methane emission also existed in the Appin colliery.

Both areas were selected for experimental projects.

Geology

The Leichhardt colliery is located 17 km south of the Blackwater township in Central Queensland. The coal measures are contained within the prolific Bowen Basin which has a sedimentary succession ranging from early Permian to Middle Triassic and consists dominantly of sandstones, shales and coals. The Permian rocks cover a major part of the basin while the Triassic rocks are limited to areas in the southern and central parts of the basin.

The Permian coals are known as the Upper Bowen Coal measures and are within the Bandana Formation. A cross section through the mines in the area is shown in Fig. 1. This cross section gives the names and distribution of the seams in the area.

This section illusrates that the two dominant seams in the Leichhardt area are the Aries and Gemini seam while the Orion seam was estimated to be only 50 cm thick. In fact the Orion seam was drilled in the Gemini 1 well and found to be 5 m thick. Aries the upper seam is not mined because of weaknesses in the roof strata. The Gemini seam is approximately 6 m thick, at a depth of 430 m and produces a prime to medium grade coking coal with an average coke yield of 81%.

The Appin Colliery is located some 35 km NW of Wollongong in N.S.W.

Coal measure deposition is confined to the

Upper Permian culminating in the widespread occurrence of the Bulli Seam over the greaterpart of the southern half of the Sydney Basin. Other coal seams (Balgownie, Cape Horn, Hargraves, Wongawilli, American Creek and Tongarra) are intermittent throughout the Upper Coal Measures. Volcanics, mainly as dykes and sills are widespread.

Overlying rocks are flat bedded multi-colored lithic sandstones (Narrabeen) quartzose sandstones (Hawkesbury) and black shales (Wianamatta) of Triassic age which form the major escarpments of the area.

Project Design

Well Locations

Although experience in the U.S.A. pointed towards no damage to roof or floor of the mine due to hydraulic fracturing it was considered necessary to prove this in each new area under investigation. Therefore one hole in each area was selected for fracturing in the working seam in a location where it should be mined through in a short period.

At Leichhardt it was decided to place three holes in such a position that they would not be mined through for some time so that information could be gathered on how long it took to establish interference between the wells. In other words how long would it take to drain the area affected by a well.

In the Appin area, many of the problems with gas are associated with goaf gas so it was planned to place holes where they could drain the lower seams and so cut down on the volume of gas released into the workings from the lower seams as the working face progressed.

It was decided that four wells in each area would be the minimum number of wells to provide the information sought. The locations of these wells are shown in Figs. 2 and 3.

Drilling and Completion of Wells

A 12 $^{1}/_{4}$" surface hole was drilled to approximately 450 m and 9 $^{5}/_{8}$" casing was cemented at this depth. To obtain maximum information from the wells it was decided to core all coal seams to obtain samples for physical analysis and to carry out desorption tests on samples to obtain data on total gas content of the individual coals as well as gather what information we could on rates of desorption.

An 8 $^{1}/_{2}$" hole was drilled 50 m below the base of the lowest coal seam, electric logs were run by Schlumberger. These included recording of hole size, formation resistivity, sonic properties, density, gamma ray and neutron. We also carried out velocity surveys to aid in seismic interpretation as well as some experimental in-seam seismic work at Appin.

After this 5 $^{1}/_{2}$" casing was cemented at total depth and the casing perforated in the coal seams using 2 $^{1}/_{8}$" Unijets with a shot density of four holes per foot. The U.S.B.M. had reported on work using both bare foot and cased hole completions (Lambert et al 1979). Cased hole completions were chosen to avoid the hole cave ins which had been reported in the case of bare foot completions. These cave ins had required a much greater frequency of workovers than was the case with cased hole completions.

The final completion of the well with a 1 $^{11}/_{16}$" plunger pump, 2 $^{3}/_{8}$" tubing, $^{5}/_{8}$" sucker rocks and a beam type pumping unit are shown in Fig. 4. This design allowed for pumping of water from the hole at rates of 5-60 bbl/day. A natural gas engine was chosen as the prime mover for the pumping unit. The down hole pump was set some 20 m below the base of the coal seam so that the coal seam would be left clear of liquid and thereby have a minimum hole pressure imposed on the formation.

Stimulation Design

The hydraulic fracture design was caried out by Halliburton Services using a computerised simulator which models the propagation of a fracture as a function of injected fluid volumes, injection rates, stimulation fluid properties, proppant type and concentration and formation fluid and rock parameters.

For a final fracture length of approx. 130 m in the Gemini seam at Leichhardt the input data and treatment design are shown in Tables 1 and 2.

Project Implementation

Drilling a Completion

Implementation of the project was fully described in a paper by Wilkinson and Barro, 1981.

Drilling and completion of the wells at both Leichhardt and Appin proceeded without undue problems as did coring and logging. Initially core recovery was low - 63% in the first core, 79% in the second but thereafter 92-100%.

When cores were brought to the surface they were immediately logged by a coal geologist and samples were taken and placed in specially constructed containers and taken to a laboratory for desorption testing.

Stimulation

The equipment layout for the foam stimulation treatment is shown schematically in Fig. 5.

For a typical job at Leichhardt the fresh water was gelled using a guar gel at a concentration of 40 lb/1,000 gal. This gel gave added viscosity to the water to help suspend the proppant in the blender tub and prevent sand settling which could lead to plugging of the pumps. The job consisted of 5 stages.

(i) 3,000 gals of foam to which was added 1 lb/gal of 100 mesh sand to plug the minute fractures and prevent fluid loss to the formation. This mixture was injected at a rate of 10 bbl/min.

(ii) The next four stages each consisted of 3000 gallons of foam with concentrations of 20-40 mesh sand at 0.5, 1.0, 1.5 and 2.0 lbs/gal added to the foam. This required adding sand to the gelled water at concentrations of 2.0-8.0 lb/gal of gel. Average treating pressure was 1-100 psi on the surface after breaking down the formation of 900 psi. After the last stage was pumped the sand laden foam was displaced to the formation with nitrogen and the well was shut in.

During the job an enzyme breaker was added to the fluid to break down the gel and the foaming agent concentration is chosen so that the foam will become unstable after a short period. If a stable foam is made it will carry the sand back into the well when the well is placed on production.

After the frac job the well was left shut in for two hours to allow the gel and foam to break. Very little sand was reproduced from any of the wells indicating that the gel and foam had broken down as designed.

The jobs at Appin were designed on the same general principles but results were somewhat different. On the first job on the Tongarra seam we were unable to break down the formation with a pressure of 4,000 psi. We suspected that the casing perforation had failed and reperforated the well without any change. We acidised the well in case the perforations had plugged but without success. We were finally able to break down the formation at a pressure of 4,500 psi and inject at 3 bbl/min at 4,000 psi.

This pressure was inconsistent with normal formation breakdown and fracturing pressures and lead us to believe that we were creating horizontal or pancake fractures. The pressures persisted in the other seams which were fractured, the Wongawilli, Cape Horn, American Creek, Balgowrie and Bulli. The Bulli seam was only fractured in the Appin-1 well and a fluorescent dye was added to the frac fluid. When headings in L panel passed the location of the well, no trace of the fracture could be found.

There is frequent disagreement among authors concerning the orientation of fractures, however, most agree that when the pressure is increased in the hole, rupture will occur in the plane perpendicular to the direction of the least compressive stress. As we were unable to find any trace of a fracture and as the formations have been subjected to additional stressing since deposition - three cleat systems are evidence of this, it is possible that the fracture created was short and chunky or possibly more than one fracture along the cleat systems. A situation such as this would tend to elevate fracturing pressures while no trace of the fracture would be found at the extremities of the pillar.

Gas Production

Typical gas production from the wells is shown in Figs. 6, 7 and 8. While the wells produce at reasonably high rates initially, up to 2,000 m^3/day, there is a rapid decline followed by a long period of stable production. Some of the high early production can be attributed to absorption of nitrogen by the coal, raising the internal pressure by some 10-20% with a consequent high initial production rate as the nitrogen is reproduced. Typical of the gas composition against time is shown in Fig. 9. The sudden drop off in nitrogen percentage is quite evident. At Appin there may be some correlation of gas rate from the lower seams as development proceeds in the overhead panels but it is not conclusive. It is expected that the gas rate will increase as longwall extraction proceeds through the area of the wells.

The graph of production from the Gemini-3 well at Leichhardt are interesting. As mentioned earlier, the Leichhardt Colliery has suffered severely from coal outbursts. These may be caused by overpressured pockets of gas and the sudden increases in production seen in September and December could be due to the radius of drainage extending to one of these pockets. Again the evidence is not conclusive. Gemini-2 also exhibits this sudden increase in production although to a lesser extent.

Water production has also been measured and it can be seen that low production rates go with high water production rates (in the same well) and vice-versa.

Coal Testing

Various tests were carried out on coal samples from each well using equipment based on that proposed by the U.S.B.M. but slightly modified to allow gas measurements to be made at atmospheric perssure and ambient temperature. The modified equipment is shown in Fig. 10.

The tests carried out were:

(a) Total gas content using constant surface pressure desorption (CSPD)
(b) Constant volume desorption (CVD)
(c) Resaturation of sample to seam pressure followed by a further CVD

The effect of temperature on desorption rate was investigated and the results are shown in Figs. 11 and 12 for initial desorption rate and total desorbed gas. At higher temperatures, the rate of desorption is higher and total desorbed gas is greater. The straight line portion of the graph in Fig. 11 can be extrapolated to determine gas lost.

The diffusion parameter ($D/S.a^2$) was also calculated from these two tests.

Desorption isotherms for the same sample as obtained from the well and resaturated are shown in Figs. 13 and 14.

Conclusions

Large volumes of gas are contained in the coal seams.

The Blackwater seams can be hydraulically fractured and results will closely follow predicted behaviour.

It is not possible to predict results of fracturing the coal seams in the Appin area with our present knowledge of stresses in the seam. We can say with a fair degree of certainty that the fracturing pattern is not what we would normally expect.

Even with the unpredictable fracturing results of the Sydney Basin coal seams, increases in gas flows do result but not to the extent that this method could be made commercial. This is done in part to the very low permeability of the coals tested.

Results from testing of the coal samples and application of the simulator described earlier by Dr. M.L. Hemala have led us to conclude that solid or in seam drainage will produce gas at much higher rates which could probably be developed to a commercial stage.

References

ELDER, C.H., & DEUL, M., 1974 - Degasification of the Mary Lee coalbed Near Oak Grove, Jefferson County, Ala., by vertical borehole in advance of mining. United States Bureau of Mines Report of Investigations, 7968.

LAMBERT, S.W., TRAVITS, M.A., & STIEDL, P.F., 1979 - Vertical borehole design and completion practices used to remove methane gas from mineable coalbed. United States Department of Eneegy, Carbondale Mining Technology Center, Report on Investigations.

STEIDL, P.F., 1978 - Foam stimulation to enhance production from degasification wells in the Pittsburgh coalbed. United States Bureau of Mines Report of Investigations, 8286.

WILKINSON, B., BARRO, L., 1981 - Coal seam degasification in Queensland utilising hydraulic fracturing with foam - A Case History.

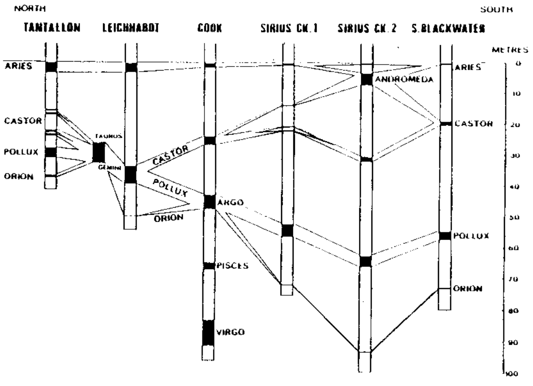
TABLE 1

SLIDE 8: WELL AND FORMATION DATA AT LEIGHHARDT COLLIERY

PERMEABILITY	0.004 md
POROSITY	0.05
YOUNG'S MODULUS	500,000 psi
RESERVOIR PRESSURE	500 psi
RESERVOIR TEMPERATURE	120°F
COAL SEAM THICKNESS	19 feet
COAL DEPTH (AVERAGE)	1,400 feet

FIG. 1

DIAGRAMMATIC CORRELATION OF UPPER COAL SEAMS SOUTH OF BLACKWATER TOWNSHIP



WELL LOCATIONS RELATIVE TO ACTIVE MINE WORKINGS

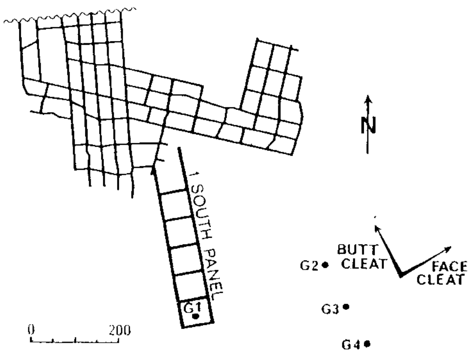


FIG. 2

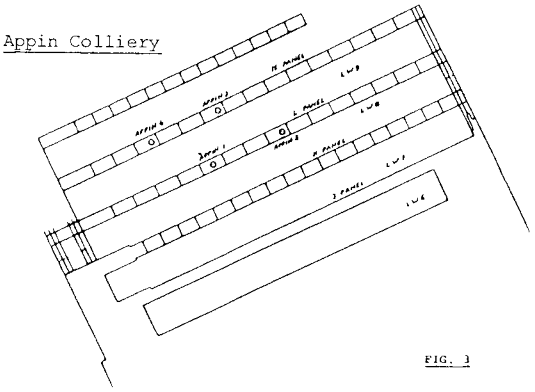


FIG. 3

CASED HOLE COMPLETION CONFIGURATION

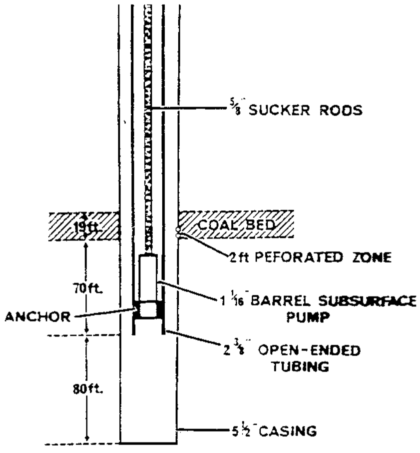


FIG. 4

SCHEMATIC DIAGRAM DEPICTING SURFACE REQUIREMENTS USED FOR FOAM FRACS

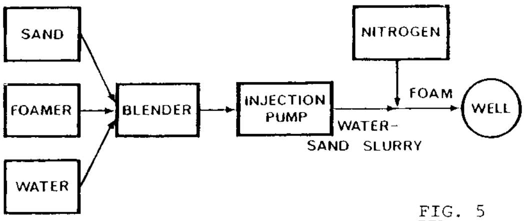


FIG. 5

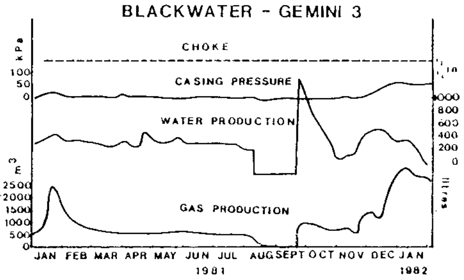


FIG. 6

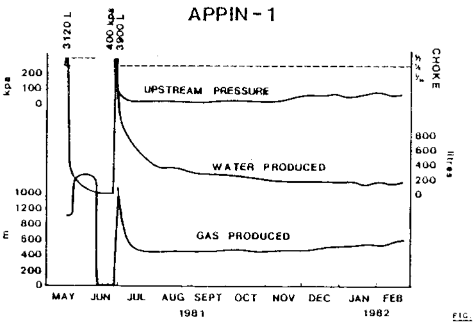


FIG. 7

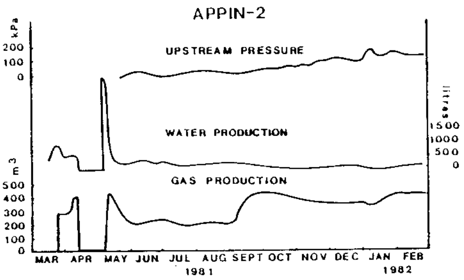


FIG. 8

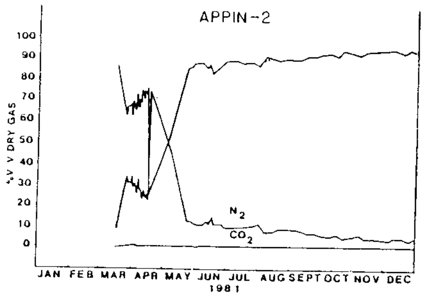
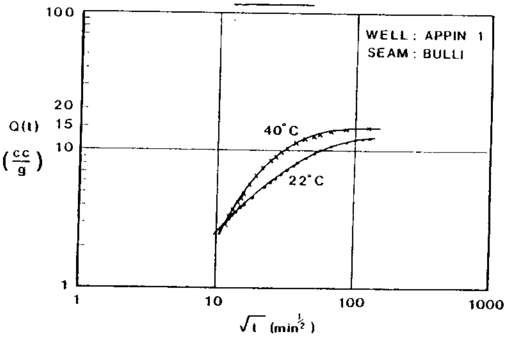
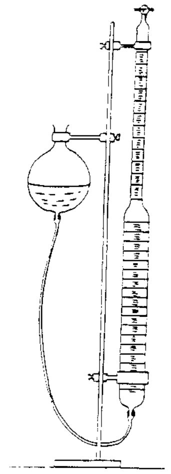


FIG. 9

THE EFFECT OF TEMPERATURE
ON TOTAL DESORBED GAS

FIG. 12





GAS VOLUME MEASUREMENT EQUIPMENT FIG. 10

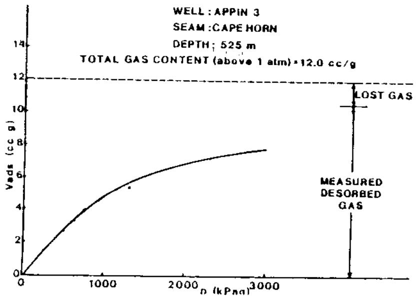


FIG. 13

THE EFFECT
OF TEMPERATURE
ON INITIAL
DESORPTION RATE

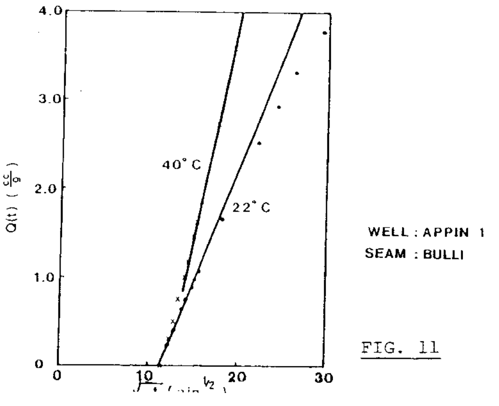


FIG. 11

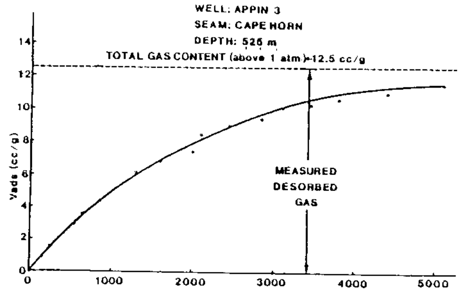


FIG. 14

TABLE 2

SLIDE 9: FOAM TREATMENT AND PUMPING SCHEDULE

STAGE NUMBER	GALLONS FOAM	SAND CONC. LB/GAL FOAM	SAND TYPE	PUMP TIME MIN:SEC
1.	3,000	1.0	100 MESH	7:09
2.	3,000	0.5	20 - 40	7:09
3.	3,000	1.0	20 - 40	7:09
4.	3,000	1.5	20 - 40	7:09
5.	3,000	2.0	20 - 40	7:09
6.	12,000 SCF NITROGEN DISPLACEMENT			3:30

LIQUID PUMP RATE	2.5 BPM
NITROGEN PUMP RATE	3,200 SCF/MIN
NITROGEN TO LIQUID RATIO	1,283 SCF/BBL
FOAM RATE	10 BPM
FOAM QUALITY	75%
NITROGEN REQUIRED	125,000 SCF
WATER REQUIRED	3,750 GALLONS

DISCUSSION

C.H. MARTIN (C.H. MARTIN AND ASSOCIATES): There is an obvious relation between the amount of water pumped and the gas flow. What is the precise nature of that? Each of the graphs showed a remarkable kick when the water output was increased.

W.J. STEWART (B.H.P. OIL & GAS DIVISION): Yes the water must be produced before the gas can start to produce, so when the water rate goes down having produced the water then the gas production goes up. Initially water is produced from the cleat system together with the gas in solution. This results in high water and gas rates. Both water and gas rates decrease after this initial spurt, thereafter as water production decreases the gas can more readily absorb from the coal resulting in a steady increase in gas production.

J. LANE-SMITH (TRIEFUS INDUSTRIES): On the figures given out on what the well had actually cost, what depth was that at?

W.J. STEWART: That was an average cost of the wells in Leichhardt, one was down to 650 m, the average was about 450/500 m. Here at Appin they run around 600 m.

J. LANE-SMITH: Was the initial diameter at the surface 311 mm?

W.J. STEWART: The hole was drilled down to about 60 m at 311 mm and 236 mm casing was cemented at that depth. A 216 mm hole was drilled to the bottom and 140 mm casing was cemented at that depth.

R. LAMA (KEMBLA COAL AND COKE): The pressure at the top of the borehole was indicated to be only a few kPa. Is it assumed that at that stage the column of the hole is free of water. Since the diameter of the hole is pretty large, is it right to assume that all the pressure loss is in the borehole or has the stimulation in fact dropped the gas pressure in the coal seam?

W.J. STEWART: The stimulation has not dropped the gas pressure, it is the continuing production that drops the pressure. It is right to assume that the borehole is to all intents and purposes empty. Right now about 8 litres a day is being pumped out, which is practically nothing. That is all that runs in. A check is made regularly with an acoustic log and it shows that the water level is down to the pump so that is 21 m below the bottom of the seam.

R. PHILLIPS (CAPRICORN COAL): With regard to the brightness and dullness of the coal, was that analysed for macerals or is that just visual observation ?

W.J. STEWART: That is just a visual observation.