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THE OCCURRENCE OF NATURAL GAS AT BALMAIN COLLIERY, SYDNEY. N.S.W.

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Brief Outline of Colliery History: A.

Bores sunk at Cremorne (on the north shore of Sydney Harbour) in 1891 struck coal at approximately 2802 feet. A company was formed to work the coal, but was refused permission to operate at Cremorne, which had been reserved for a residential area. A site at Balmain was secured, and the Birthday Shaft was sunk to depth of 2,937 feet between 1897 and 1902.

The 10 - ft. coal seam at Cremorne was found in the Birthday Shaft to be represented by two seams of low-grade coal, 2'4" and 8" thick, separated by a 3'2" band of carbonaceous shale. As these seams could not be worked at a profit, two headings were driven in the direction of Cremorne. The seams gradually thickened, with decreasing thickness of the shale parting, and merged into a single seam 4'7" thick, containing 1.1/2" of splinty coal 2' from the floor, at a distance of 4,100 feet from the shaft.

Coal mining started about 300 feet beyond this point in 1910, but difficulties were encountered from the first owing to the gassy nature of the mine, difficulty of maintaining adequate ventilation, long haulage, and heavy hoisting costs. At one stage the colliery was handed over to the miners, but as they also were unable to operate at a profit, the mine was finally abandoned in 1931.

During the period 1932-1937, Natural Gas and Oil Corporation Ltd. put down a bore below the bottom of the Birthday (Downcast) Shaft to a depth of 4,935 feet. Eight - inch casing was run from the surface to 3,006 feet. Inside this, 6 - inch casing was run from the surface to 4,170 feet. Small shows of gas were encountered, some of the lower shows containing up to 3 percent of ethane and higher homologues. Attempts to increase the flow of gas by acidizing and the use of explosives were unsuccessful, the bore was junked below the casing shoe and operations were suspended.

With petrol in short supply during the war, Natural Gas and Oil Corporation set out to prevent the escape of methane from the mine. Seals were constructed in the headings near the bottom of the Downcast shaft, in 1943-44 but in the absence of accurate mine plans and with heavy rock falls hindering exploration, it was some time before all the headings were sealed off. A 6 - inch pipe extended through the main seal, and this was connected to the existing 6 - inch casing by nine 2 - inch pipes. From the point of view of gas flow, this connection is highly unsatisfactory.

Apart from a seepage about 60 feet and a small flow of water about 700 feet, the mine was dry. A pump was installed at 800 feet, and the lower part of the shaft was kept water-free during the mining period. Between 1931-1942, water collected to a depth of 5 feet in the stable drive and the back heading leading to the Upcast shaft, and to a depth of 1.1/2 feet in the main heading near the engine room entrance. Although water was constantly falling like rain, and could also be heard trickling down the shaft walls, the level was reported to be constant during 1943-44. One observer stated that the water rose to the level of the coal seam, and then seeped away through the coal.

Construction of seals in headings containing water was a hopeless task from the first; the ground adjacent to the headings had become water-logged, rendering the rock-shale mass highly unstable as a foundation. In spite of continuous maintenance, the seals could not be kept intact. Even if the seals had been effective, the fractured shale in the upper walls and roof of the headings would have permitted gas to escape or air to enter, and vacuum could not have been applied. Also, if the coal seam was permeable to water, it was highly permeable to gas.

In an attempt to prevent the entrance of air during pumping operations, seals were constructed at the top of the shafts. Although these seals were made air-tight nothing was done to seal off ground adjacent to the shafts; gas escaped to atmosphere, and air was only prevented from entering by keeping gas pressure in the shafts above atmospheric pressure.

Although the depth of the shaft has been given as 2,937 feet, it is possible that this depth refers to the base of the sump, and if so, the sump-top elevation is unknown. The main coal is logged between 2,880 and 2,886 feet, a band of coal 1'8" thick occurs at 2,916 feet, and a 3" seam of cannel coal was found at 2,934 feet. Which coal now marks the limit of water rise is not known, possibly the 1'8" band.

2. Recovery of Gas.

Prior to the installation of top seals, the highest commercial recovery of gas was 1,262,345 cubic feet during the four weeks ended 13/9/45, an average daily recovery of 45,100 cubic feet. During this stage gas was recovered each day through the 6" Riser until an excess of oxygen in the gas made further pumping unsafe. Leakage of air into the gas system presumably occurred at the bottom seals when gas pressure fell below air pressure in the shaft.

During and subsequent to the construction of top seals, demand for gas fell off sharply and the highest recorded recovery with the seals in place, was 138,765 cubic feet for the week ended 18/7/45, an average daily recovery of about 20,000 cubic feet.

With a waning market for bottled methane, the colliery owners tried to interest Australian Gas Light Company in the project, on the grounds that methane could be used as a substitute for imported gas oil in the enrichment of water gas.

References.

The gas flow was tested by Australian Gas Light Company in January, 1946, and estimated to be between 3,400 and 6,200 cubic feet per hour. As this quantity was far below the estimated economic minimum,(500,000 cubic feet per day), the project was dropped. B.

To guard against the possibility of air entering the shaft past the top seal and forming an explosive mixture, a differential of 0.5" water gauge above atmospheric pressure is maintained at shafthead in accordance with instructions issued by the Department of Mines.

3. Leakage of Gas.

The pressure of gas in the vicinity of shafthead, and the sound of escaping gas which is heard when shafthead water gauge reading exceeds 1", prove that gas is escaping from the shaft to atmosphere.

The log of the Downcast shaft starts as follows:- C.

Birthday Shaft (Downcast Shaft) Surface elevation, 80' above sea level.

Strata	Thickness	Depth from Surface.
Brickwork	7' 0"	7' 0"
Gritty ferruginous sandstone	32' 2"	39' 2"
Shaly Sandstone	4' 0"	43' 2"
Shale parting	0' 1"	43' 3"
Sandstone	49' 8"	92' 11"
Sandy shale	5' 5"	98' 4"
Sandstone	1' 9"	100' 1"

Since the colliery is at bayside, the freedom from salt water indicates that the strata are mainly impervious. It appears likely that gas leakage is confined to the filled zone, 0 - 7', but it may continue into the weathered zone of the gritty ferruginous sandstone, 7' - 39'2". The presence of a seepage at 60' probably indicates a fissure extending to surface.

It has been suggested that a high leakage rate is responsible for the low commercial recovery, and that in the absence of a suitable method for measuring leakage, it is impossible to determine the optimum rate at which gas is available from the workings.

4. Volume of Shafts and Workings.

Free intercommunication of the two shafts at base has been proved by the A.G.L. flow test on 9th January, 1946; the shafts are 18 feet in diameter, and 2,937 feet deep, and two headings of unknown size extend about 1,100 feet in the direction of Cockatoo Island. The combined volume is at least 1.5×10^6 cubic feet, and may be 1.6 million.

The volumetric capacity of the workings behind the bottom seals, comprising the headings extending in the direction of Cremorne and the worked-out section of the colliery, is unknown. By scaling-off the mine plan, a maximum possible capacity of 22,000,000 cubic feet is obtained.

Mining was carried out by the advancing longwall method, which would remove all coal; presumably props were withdrawn as the coal face advanced, and, as the roof consisted of shale, sandstone and conglomerate, falls would shortly occur. While the aggregate space would not be reduced by fallen material, the effective space for gas storage and flow would be substantially reduced. In some places falls of rounded or angular material would leave interstices through which gas could freely pass; in others, shale would break down and increase in volume until the zone became completely blocked. The geological section overlying the workings contains no competent stratum, and progressive falls would occur until all head-room had been filled.

Coal mining commenced in 1910, and the colliery was finally abandoned in 1931. Judging from the falls observed near the shaft, it is highly probable that the entire mine is blocked to some extent, but it is reasonable to assume, that a zone immediately in front of the coal face is comparatively open.

5. Yield of Gas during the Mining Period.

It is on record that during mining operations the percentage of gas to air in the ventilation stream varied with barometric change. The mine was very gassy, and large volumes of air were circulated to keep the proportion of gas to air within the limits prescribed for safety. Since the inbye air travelled along a heading which followed the coal seam, it was probably contaminated by gas before it reached the working face.

References.

Originally, the mine yielded 1,000,000 cubic feet of gas daily, a volume confirmed by colliery inspectors' records of air-stream analyses. It is believed that this gas was originally held on the surfaces of minute coal grains by adsorption, and that it was released therefrom by decreasing pressure. After release, it became a free gas in a permeable stratum subject to ordinary laws of gas flow. Thus, while part of the Balmain gas yield was derived from the daily coal recovery, most of it probably came from the coal face, and it is this flow, much reduced, which now provides gas for compression. However, if the effective permeability of the coal was low, the greater part of the gas yield could have been derived from the daily winning; in such a case it is reasonable to expect that the colliery inspectors would have noticed that the gas yield was dependent upon two factors, barometric pressure and tonnage mined.

In the absence of information relating to effective permeability of the coal and original pressure of the gas (i.e. the pressure at which adsorbed gas ceased to be released from the coal) it is impossible to relate pressure drop and gas yield with any degree of accuracy. That pressure existed is shown by a burst of gas which filled the shaft to the 1,200 ft. level after a shot had been fired in a sandstone at 2,920 feet, during shaft-sinking operations. That the pressure was comparatively low is shown firstly by the low rate of gas yield when pressure in the workings was atmospheric pressure plus the head of a column of air 2,937 feet high, and secondly by the variation in rate of yield with changes in barometric pressure. Alternatively, the pressure might have been reasonably high and the effective permeability of the coal low, but this interpretation would not provide so satisfactorily for variation in yield with changes of barometric pressure.

Gas was encountered at 4,177 feet in the bore, which had a closed in gauge pressure of 16 pounds per square inch, or about 31 pounds per square inch absolute. It is unlikely that gas pressure in the main coal seam at Balmain exceeded this value. D.

Since release of pressure is necessary to free adsorbed gas from the coal, while pressure is required to displace the freed gas towards the coal face, it follows that only the coal adjacent to the workings will have lost all its adsorbed gas, and that the percentage of the original adsorbed gas still in situ progressively increases with distance back from the face.

If, as has been assumed, the original gas pressure was low, the drop in gas yield over the years may be attributed to the setting up of pressure equilibrum within the coal, under which the pressure required to displace freed gas towards the coal face is almost sufficient to prevent the release of adsorbed gas. If this hypothesis is correct, the application of vacuum could be expected to result in increased yields of gas, but the extent of the increase and the duration of flow at the increased rate will both be ultimately dependent upon the effective permeability of the coal.

6. Yield of Gas without Top Seals.

After the construction of bottom seals, gas was drawn from the 6" Riser and sold either in bottles or bulk. The quality of gas, i.e., the degree of dilution with air, was stated to vary with barometric pressure. This may be interpreted as meaning that attempts to force recovery of gas when the barometer was high invariably resulted in the admission of air from shaft bottom to the headings behind the seals.

Daily recovery rates are only available in this office for a short period during August - September 1944. The highest recovery shown is 77,800 cubic feet on Monday, 21st August, but as the plant had been shut down for maintenance on Sunday and had not operated on Saturday afternoon, the high yield was almost certainly the result of accumulation of gas in the workings. The next highest yield was 55,620 cubic feet on 23rd. August, with air not exceeding 4%; if an average value of 2 percent is allowed for air, the net yield was about 2,270 cubic feet per hour. The lowest yield was 43,390 cubic feet on 15th August, when the air content was between 10 and 12 percent all day; after correcting for air, the net gas yield was 1,610 cubic feet per hour. Since air was present in the gas throughout both days, it is apparent that gas pressure in the workings was below air pressure at the base of the shaft; no leakage of gas was possible under these conditions, and the net yields represent optimum recoveries under the barometric pressures then existing.

It would be unreasonable to assume a 40 percent increase in yield rate with a change of 1 or 2 inches in barometric pressure; it would be equally unreasonable to postulate that abnormally high and low barometric pressures existed when the yield rates were 1,610 and 2,270 c.f./h. respectively. If values of 410" and 401" w.g. absolute are taken for average high and low barometric pressures, the relative absolute pressures in the workings would be 452.76 and 441.87" water gauge, less unknown values to account for admission of air.

With this assumption, prior to the construction of top seals the yield of gas varied from about 1,600 to 2,300 c.f./h. with an apparent pressure drop of 10.89" w.g. between pressure limits of 452.76 and 441.87" w.g. absolute in the workings.

7. Yield of Gas with Top Seals.

With the top seals in place, a column of gas with density 0.5948 at N.T.P. replaced air in the shaft. With barometric pressures of 410" and 401" w.g. absolute at surface, and with the addition of 0.5" w.g. safety differential, absolute pressures in the workings would have been 435.38 and 425.27" w.g. respectively.

References.

In so far as the yield of free gas is concerned, the variation in yield over a short time interval with change of pressure will probably conform to Darcy's Law for linear displacement of gas through permeable strata, which may be written as follows:- E.

$$Q = C \quad (P_1^2 - P_2^2)$$

Where Q - quantity in cubic feet per unit of time

P_1 - pressure in the coal in pounds per square inch absolute

P_2 - pressure in workings in pounds per square inch absolute

C - the product of various factors which remain constant, in the given circumstances, while Q, P_1 and P_2 vary.

It follows that the ratio of two rates of flow may be shown -

$$\frac{Q_{12}}{Q_{13}} = \frac{(P_1^2 - P_2^2)}{(P_1^2 - P_3^2)}$$

If values for Q_{12}, Q_{13}, P_2 and P_3 are applied from (6) above, the value of P_1 is found to be 17.28 P.S.I.A.: relative values of P_2 and P_3 are 16.58 and 15.96 P.S.I.A. Since these values are based on loose assumptions regarding barometric pressures existing during the recovery period, they have no factual value. However, they may be used to determine the rates of yield which should have existed after the construction of top seals, <u>in relation to</u> the measured yields of August, 1944.

With this basis the yields for pressure of 435.38 and 425.27" w.g. absolute are 2,650 and 3,240 cubic feet per hour respectively. Since the top seals were not completed until June 1945, there may have been a slight reduction in P_1 tending to reduce these relative values; it is believed, however that the drop in pressure would be negligible. The distance to be travelled by the gas through the coal would certainly be slightly increased; taking all factors into consideration, a reasonable margin either way should be allowed on the values shown.

If data were available for plotting gas yield against time to give a production decline curve, it would probably be found that at the present time this curve is approaching a straight line, almost parallel with the horizontal axis.

8. <u>Physical Aspects of Gas Reservoir System.</u>

The mine may be considered as a gas reservoir, comprising two inter-connected shafts with headings and workings imperfectly separated from these shafts by bottom seals. Gas is released from the coal and stored in this reservoir, the pressure within the reservoir gradually rising until the rate of leakage equals the rate of release. Since this pressure is measured on a manometer, the reading will vary with barometric change and must be expressed in terms of absolute pressure to obtain a true value for the gas pressure within the system.

Two control points affect the storage of gas in the reservoir system -

(a) the bottom seals, which restrict the flow of gas from workings and headings into the shafts; the flow may be through the seals, or through permeable strata adjacent to them.

(b) the ground at surface, which restricts the escape of gas from the shafts.

Since there is no evidence of abnormal conditions, it is reasonable to postulate that gas in the reservoir system conforms to general gas laws, and to base calculations of recovery on those laws. Flow at the above-mentioned control points may therefore be assumed to conform to Darcy's law which has already been outlined in (7) above.

It has been shown that the ratio of two rates of flow may be expressed -

$$\frac{Q_{12}}{Q_{13}} = \frac{(P_1^{\,2} - P_2^{\,2})}{(P_1^{\,2} - P_3^{\,2})}$$

Since the Department of Mines has ordered that the shafthead pressure relief valve shall be manipulated to give maximum and minimum water gauge readings of 3" and 0.5" respectively, $P_1 - P_2$ will vary between 0.108 and 0.018 pounds per square inch absolute, and for these low values the ratio may be written -

References.

$$\frac{Q_{12}}{Q_{34}} = \frac{P_1 - P_2}{P_3 - P_4}$$

, with a maximum possible error of 2%, and the pressure values may be given in inches of water gauge.

Leakage may therefore be assumed to be directly proportional to drop in pressure between shafthead and atmosphere; i.e. to shafthead water gauge readings. Similarly, flow into the shafts from behind the bottom seals will be directly proportional to drop in pressure across the seal. Since a higher shafthead differential is required for increased leakage, a higher pressure drop will be necessary across the bottom seal when leakage is high.

Tests made by Australian Gas Light Company have never disclosed any difference between densities of shaft and 6" Riser gases; the pressure drop necessary to cause flow from workings to shaft under static conditions will therefore be indicated by the difference between shafthead and 6" Riser water gauge readings, after applying a correction for the increased value of head resulting from the pressure differential.

Under static conditions, the value of H, with gas density 0.5948 at N.T.P., is 25.50" when the pressure at shafthead or Riser is 4.5" w.g. absolute. The value of H at lower absolute pressures is given by - F.

$$H = 25.50 - 0.1233 \ (415 - P)$$

Thus with barometric pressure of 407" w.g. absolute, 1" w.g. on shafthead and 3" w.g. on 6" Riser, the relative values of H are 24.64 and 24.88", and the pressure drop across the bottom seal is 2.24" w.g.

The temperature gradient at Balmain is given as 1°F. per 90.7 feet, the temperature ranging from about 63°F. at the zone of constant temperature, assumed to be 15 feet below shafthead, to 95°F. at bottom. The gas density is taken as 0.5948 at N.T.P. The volume of workings and mean average shaft gas when expressed in volume of gas at N.T.P. are - G.

Shafthead or 6" Riser absolute pressure.	Volume of mean shaft. gas	Volume Workings gas	Volume at N.T.P.
415" w.g.	1 c.f.	-	0.995 c.f.
400	1	-	0.993
415	-	1 c.f.	1.014
400	-	1	0.976

while volumetric ratios between mean shaft gas and workings gas, converted to N.T.P., are -

Surface absolute pressure.	Volume of workings gas	Volume mean shaft gas
415" w.g.	1 c.f.	1.020 c.f.
400	1	1.022

It is apparent that for small flow rates, corrections for temperature and pressure can be ignored without introducing appreciable errors.

9. General Observations and Assumptions.

(a) With all valves closed, water gauge readings at shafthead and 6" Riser vary with barometric change, but the absolute pressure increases in the system within limits.

This increase in absolute pressure proves that the RELEASE RATE (rate of release of gas from coal) exceeds LEAKAGE RATE at low values of shafthead water gauge.

(b) The quantity of gas at N.T.P. entering the system to give an observed rise of absolute pressure in unit time may be termed the INCREMENTAL RATE.

Given that all valves are closed, the sum of LEAKAGE and INCREMENTAL RATES, at any given time, will equal RELEASE RATE, and this relationship will hold with positive values until, with increasing LEAKAGE RATE, the INCREMENTAL RATE reaches zero. With higher Leakage Rates, the values of INCREMENTAL RATE are negative.

(c) The graph of LEAKAGE RATE against pressure drop is a straight line; that of RELEASE RATE cannot be plotted, but within the limits of absolute pressure prevailing during the tests may be assumed to approach a straight line. Accordingly, the graph for INCREMENTAL RATE will also approach a straight line.

(d) Since the RELEASE RATE equals INCREMENTAL plus LEAKAGE RATE at any given time, within the limitation shown in (b) above, it should be possible to withdraw gas from the system, by pumping or open flow, at a rate not exceeding the INCREMENTAL RATE without causing any reduction in absolute pressure in the reservoir system.

It follows that where a RECOVERY RATE (rate of pumping or gas flow) causes a drop in absolute pressure, in the reservoir system, that rate exceeds the INCREMENTAL RATE for the existing absolute pressure and shafthead water gauge values.

(e) Since there is resistance to flow across the bottom seal, increased leakage from the shaft will necessitate a higher pressure differential between workings and shaft to compensate for the amount of increase in leakage. It follows that with all valves closed, increasing leakage will be accompanied by increased difference between shafthead and 6" Riser absolute pressures. In other words, falling barometric pressure will cause less drop in workings absolute pressure than is shown by shaft absolute pressure, and the full range of barometric pressure decrease will not be reflected by proportionate increase in RELEASE RATE.

(f) Since the area of coal face exposed at base of the shafts and in the Cockatoo Island headings is negligible by comparison with that exposed in the workings and main headings, it may be assumed that gas leaking or withdrawn from the shaft has been wholly derived from behind the bottom seals.

(g) The RELEASE RATE is assumed to vary with barometric pressure; mean values in 1945, as shown in (7) above, should have been -

Absolute pressure in workings.	Release Rate.
435.38" w.g.	2,650 c.f./h.
425.27" w.g.	3,240 c.f./h.

(h) Under static conditions and in terms of N.T.P., the density of gas in the shaft is assumed to be the same as that of gas in the 6" Riser, and at any given time the heads of the two/gas columns will vary proportionally to the difference in water gauge readings.

(i) The test readings upon which calculations of Recovery and Leakage Rates are based will only be accurate within fairly wide limits. Some of the possible sources of error are -

Barometric Pressure: For the tests in January, 1946, a barograph was installed at shafthead and set at a pressure value communicated by telephone from the Weather Bureau; check pressures were obtained from the Weather Bureau each day.

Later in 1946 a set of barometric readings, corrected to 80 feet above MS.L., was obtained by the writer from the Weather Bureau. These values differed appreciably from the corrected barograph readings; the barograph readings were then rechecked, and the revised values also showed considerable divergence from those originally used.

For the February, 1947, tests a mercury barometer was installed adjacent to shafthead, and readings were corrected and converted to water gauge. The instrumental error was 0.002" Hg., but the liability to personal error was much higher owing to bad lighting.

While the water gauge readings should reflect barometric change, there was no apparent agreement between the barometer and the water gauges. With calibration over a period of time, the error due to lag could be computed and a correction applied, but the need for this was not recognised prior to the February Tests.

Bailey Meter: Believed to be accurate to within 2 per cent, but the recorded flows are subject to correction for zero, temperature, pressure and gravity. The flow values shown on the charts of January tests have apparently been read direct from the Bailey Meter chart, no correction being required for zero. The flow rates given for the February tests are corrected values supplied by Australian Gas Light Company.

Micro-Manometer: Used in the January tests, and probably accurate to 0.005".

Inclined Manometer: Used in both sets of tests, and probably accurate to 0.025".

Ordinary Manometer: Used in the February tests, and probably accurate to 0.1".

Tubing: Half inch rubber tubing was used for connections between gas lines and instruments. Water, possibly left in the tubing from some previous test, possibly condensed from vapor produced with gas, collected in slugs and caused violent fluctuations in the manometers before its presence was detected and remedial action taken.

Observational Errors: The January tests were conducted by skilled officers of Australian Gas Light Company and a high degree of accuracy was achieved. Some of the observers in the February tests were less competent, and personal errors occurred. For most of the time only one observer was on duty; it was impossible then to take synchronous readings, or to take readings at short time intervals.

Lag in Gas System: While it is assumed that pressure changes equally throughout fluid contained in a vessel, lag of from 3 to 6 minutes is shown by time-pressure readings at Downcast and Upcast Shaftheads during the flow test on 9/1/46. A correction can be applied for lag in this instance, but no data is available for lag between the main workings and 6" Riser Head.

Temperature of Gas from 6" Riser: This was not taken during the January test, and the installation made for the February test proved unsatisfactory. Accurate gas temperature readings are necessary when correcting the Bailey meter recordings.

10. Observations on Incremental and Leakage Rates.

It has been assumed that gas may be withdrawn from the reservoir system at any given time at a rate not exceeding the INCREMENTAL RATE, without causing a drop in the absolute pressure of the system, and it has been shown that the LEAKAGE RATE should vary in direct proportion to the pressure drop between shafthead and atmosphere.

(a) Flow Test; 25/2/47:

	Time hours	Shafthead	Workings absolute pressure	Bailey Meter Recovery Rate
Start	1117	0.80" w.g.	435.92" w.g.	4,000 cf
Finish	1555	0.45	435.03	2,300

Since the absolute pressure of the reservoir system was increasing prior to 1117 hours, it is apparent that RELEASE RATE then exceeded LEAKAGE RATE

The RECOVERY RATE was progressively reduced to 2,300 c.f./h. over a period of 2.1/2 hours, and maintained at this rate for 2 hours. At the end of the test the absolute pressure of the reservoir system was still falling, but slowly, indicating that the INCREMENTAL RATE was slightly less than 2,300 c.f./h. with 0.45" shafthead w.g. and 435.03" w.g. absolute in the workings.

The LEAKAGE RATE at 0.45" w.g. would be 56% of that at 0.80" w.g., an effective reduction of 44%. It is apparent that if leakage had a sufficiently high value at 0.80" w.g., this reduction of 44% would compensate for the observed recovery rate of 2,300 c.f./h. and there would be no fall in absolute pressure in the reservoir system at 0.45" w.g. It follows that the LEAKAGE RATE at 0.80" w.g. must have been less than 5,200 c.f./h., whence at 0.45" w.g. it must have been less than 2,900 c.f./h.

(b) Flow Test; 26/2/47:

	Time Hours	Shafthead	Workings absolute pressure	Bailey Meter Recovery Rate.
Start	1030	1.27" w.g.	437.11" w.g.	3,000 c.f.
Finish	1500	0.88	436.36	2,065

Since the absolute pressure of the reservoir system was increasing prior to 1030 hours, it is apparent that RELEASE RATE then exceeded LEAKAGE RATE.

The RECOVERY RATE was progressively reduced to 2,400 c.f./h. over a period of 2.1/2 hours; the pump was then stopped, and gas permitted to flow under its own head from the 6" Riser. The RECOVERY RATE under natural flow commenced at 2,125 c.f./h., fell uniformly, and had a final value of 2,065 c.f./h. after 2 hours. At the end of the test the absolute pressure of the reservoir system was still falling indicating that the INCREMENTAL RATE was less than 2,065 c.f./h. with 0.88" shafthead w.g. and 436.36" w.g. absolute in the workings.

The LEAKAGE RATE at 0.88" would be 69% of that at 1.27" an effective reduction of 31%. The LEAKAGE RATE at 1.27" must accordingly have been less than 6,600 c.f./h., whence at 0.45" w.g. it would have been less than 2,300 c.f./h., a decrease of 600 c.f./h. on the limiting value determined in (a) above.

(c) Pressure Rise Test; 25/2/47:

At the close of the Flow test all valves were shut and observations made of pressure rise in the Downcast Shaft and workings.

	Time Hours	Shafthead	Absolute Pressures Shaft mean	Workings.
Start	1615	0.45" w.g.	421.75" w.g.	435.12" w.g.
	2315	1.05	422.77	436.74
Finish	2415	1.25	422.87	436.92

(i) Pressure rise has been plotted against time, and values of INCREMENTAL RATES computed from the curves, giving -

Time Hours	Shaft Incremental Rate	Workings Incremental Rate	Workings absolute pressure
1615	796 c.f./h.	689 V x 10^{-6}	435.12" w.g.
2316	372	433 V x 10^{-6}	436.74

(ii) The INCREMENTAL RATE has been shown in (a) above to be slightly less than 2,300 c.f./h. at 0.45" shafthead w.g. and with 435.03" w.g. absolute in the workings; since change in RELEASE RATE would be negligible with pressure change from 435.03 to 435.12", a value of 2,250 c.f./h. may be taken to determine the volume of the workings, which is found to be 2.11 x 10^6 cubic feet.

Since a change of only 0.05" w.g. in the pressure reading would give a volume of 20% higher or lower, the value shown for workings volume may be considered as an approximation only.

(iii) Since the RELEASE RATE varies with barometric change, it is apparent that this rate will decrease slightly with increase in workings pressure from 435.12 to 436.74" w.g. absolute in this test; at the same time, LEAKAGE RATE will increase proportionally to the change in shafthead water gauge readings. There is no present guide to the relationship of RELEASE RATE and workings pressure but it is permissable to take maximum and minimum values.

(iv) Assuming 100% increase in flow rate with reduction of 11" w.g. in workings pressure, the decrease applicable to this test is 15%. Since RELEASE RATE is the sum of LEAKAGE and INCREMENTAL RATES, the value of LEAKAGE RATE can be resolved proportionally, and is found to be 425 c.f./h. at 0.45" w.g.

	1615 Hours	2315 Hours
Leakage Rate	425 c.f./h.	990 c.f./h.
Inc'l Rate, Shaft	796	372
" " Workings	1454	912
Release Rate	2675 c.f./h.	2274 c.f./h.
Abs. Pressure in Workings	435.12"w.g.	436.74" w.g.

The yield has decreased by 15% during the period 1615-2315 hours.

(v) Assuming 100% increase in flow rate with reduction of 40" w.g. in workings pressure, the decrease applicable to this test is 4%, and LEAKAGE RATE is found to be 640 c.f./h. at 0.45" w.g.

	1615 Hours	2315 Hours
Leakage Rate	640 c.f./h.	1491 c.f./h.
Inc'l Rate, Shaft	796	372
" " , Workings	1454	912
Release Rate	2890 c.f./h.	2775 c.f./h.
Abs. Pressure in Workings	435.12" w.g.	436.74" w.g.

(d) In (7) above the rate of gas yield, deduced from meausred flow during August-September 1944, was estimated to be 2,650 c.f./h. at 435.38" w.g. absolute. The value now calculated on the basis of flow and pressure rise tests ranges from 2,675 to 2,890 c.f./h. at 435.12" w.g. absolute.

While there is fair agreement between the yield rates, there is room for error both in the assumptions and the computation. The rates are probably correct to within 25% either way, but their principal value lies in showing that leakage is comparatively unimportant when there is a low pressure differential between shafthead and atmosphere.

While on the subject of leakage it is relevant to point out that during the pressure rise test on 25/2/47, with shafthead water gauge showing 0.60", Mr. Wiggington was asked to test for gas leaks. Using a blanket to prevent dispersal of gas by air currents, he was unable to get a positive test for methane with the safety lamp.

(e) While the RELEASE RATE is assumed to vary within narrow limits with barometric change (the variation shown by the August 1944 recovery values was about 40 per cent), LEAKAGE RATE will vary within comparatively wide limits, its value at 2" shafthead w.g. being 4.44 times the value at 0.45" w.g. It follows that LEAKAGE RATE must be small by comparison with INCREMENTAL RATE at 0.45" w.g. to enable pressure to build up in the reservoir system. Also, unless LEAKAGE RATE is negligible at 0.45" w.g., it is possible that with increasing leakage the INCREMENTAL RATE becomes zero within the range of pressures recorded in the tests.

Although low barometric pressure is reflected in high water gauge readings and is accompanied by increased leakage, the barometer never remains constant long enough to allow absolute pressure in the reservoir system to reach equilibrium, when LEAKAGE RATE equals RELEASE RATE, and INCREMENTAL RATE is zero. Since rising barometric pressure is accompanied by a reduced LEAKAGE RATE and favourable conditions are provided for building up pressure in the reservoir system, it is reasonable to postulate that the nearest approach to equilibrium will be found at or shortly after the point of maximum barometric pressure following upon a reasonable period of barometric pressure rise.

Since leakage varies with change in shaft head water gauge while gas release from coal varies with change in workings absolute pressure, no method of calculating equilibrium point has so far suggested itself.

11. Observations on A.G.L. Flow Tests from Shaft, 9/1/46:

(a) The chart accompanying the report on these tests must be compared with charts from Thorp Pressure gauges, installed in the Downcast and Upcast shafts, to obtain a true picture of the behaviour of shaft pressure during and after the flow period. The "Upcast" chart shows smooth curves for both flow and recovery periods, while the "Downcast" chart shows instantaneous pressure drops and pressure rises at the commencement and end respectively of the flow tests. It seems probable that the take-off for the Thorp gauge on the Downcast shaft was located on the 4" exhaust pipe erected for the test, and that the initial sharp drop represents pressure differential necessary to cause flow, while the final sharp rise represents equalization of pressure at termination of flow test; since drop in pressure at the Upcast shaft lagged behind that at the Downcast shaft, this final equalization of pressure is due partly to establishing pressure equilibrium in the two shafts, and partly to termination of flow.

References.

(b) With this initial sharp rise eliminated, the pressure curve shows progressive reduction in the rate of pressure increase. The nature of this curve suggests equalization of pressure between workings and shaft, and this interpretation is supported by the drop in absolute pressure in the workings during this period. The withdrawal of gas from the 6" riser immediately prior to and during the tests confuses the issue, but the curves show that absolute pressure in the workings remained fairly constant during the initial stages of shaft flow, and dropped sharply during the final stages of flow; the behavior of the curves indicates that flow from workings to shaft increased with rise in differential pressure, and may be taken as proof that there is resistance to the flow of gas through or around the bottom seal.

(c) The difference between shafthead and 6" riser water gauge readings at the commencement of the first flow period, about 1.28", does not represent a static condition; the compressor had drawn gas from the 6" Riser during four periods prior to the test, thereby disturbing shaft-workings equilibrium.

(d) The report on these flow tests gives average flow rates of 11,000 and 12,500 cubic feet/hour respectively, based on Fanning's equation. Relative average values, based on Spitzglass' equation for low pressure gases, are 8,500 and 9,900 cubic feet/hour respectively. It is apparent that the former set of values cannot be challenged on the grounds of being too low. The curves are too confused by intermittent withdrawals of gas from the 6" Riser to attempt reconciliation between flow and release rates, and observed pressure drop in the reservoir system. H.

12. Observations on A.G.L. Flow Test from Shaft, 10/1/46.

(a) Flow values for this test are given in the report as 7,200 c.f./h. at start, reducing to 5,500 c.f./h. after 1.1/2 hours and kept approximately constant at the latter value for about 4 hours. Relative values, based on Spitzglass' equation, are 6,000 and 4,800 c.f./h. The shafthead water gauge reading dropped from 1.80 to 1.02" in the first 1.1/2 hours and fluctuated within limits of 1.05 and 0.97" over the remainder of the period.

(b) The shafthead pressure curve is steep at the commencement (Recovery rate and Leakage rate then have maximum values) and progressively flattens with reduction in flow rate and Leakage rate over the initial period of 1.1/2 hours; during the final period of about 4 hours, with Recovery rate and Leakage rate practically constant, the pressure curve is a straight line. The nature of this curve supports the assumption that the Leakage rate is proportional to the pressure differential between shafthead and atmosphere. Barometric pressure fell sharply during the test.

(c) The workings pressure curve shows little change in the first half hour of flow, reaches a maximum about 1.1/2 hours later, and thereafter continues more or less as a straight line except where interrupted by gas compression operations. The behaviour of this curve indicates that with a drop of 1.4" w.g. in the workings absolute pressure, the resultant increase in the rate of release of gas from coal is negligible by comparison with the measured flow rate, 4,800 cubic feet/hour.

(d) Using the values of leakage, release rate and workings volume shown in (10) above and applying margins of 25%, reconciliation between measured withdrawals of gas and the observed pressure drop in the reservoir system is readily obtained for this test.

13. Observations on A.G.L. Pumping Test from 6" Riser, 15/1/46.

Owing to a draughting error, Figure 2 accompanying the A.G.L. Report is misleading; the initial absolute pressure on the 6" Riser is shown as 410.75", but the correct value (based on test observations), is 411.71". The pressure rose to 411.85" at 29 minutes, and then dropped to 410.89" when the first compression stage commenced. Also, owing to an unfortunate choice of scale, the changes in 6" Riser and shafthead absolute pressures are difficult to determine; for instance, the log of 6" riser water gauge readings shows falling pressure accompanied by falling barometer and decreasing flow rate during the first compression stage, but this is not apparent in the pressure curve. The data has accordingly been re-plotted, using barograph readings corrected to agree with Weather Bureau recordings at 9 a.m. and 3 p.m., these in turn having been corrected for station level of 80 feet above M.S.L.

(a) Both pressure curves show an upward trend during the period 9-29 minutes, indicating that RELEASE RATE then exceeded LEAKAGE RATE. This points to a value of 500 c.f./h. or less for leakage rate at 0.45" w.g., based on the relationship shown in (10) above.

(b) Pressure values during and after the compression stages were -

Time Hours	Shafthead w.g.	Shafthead Absolute Pressure	Compressors Working	Absolute Pressure drop related to 30 minute period	Difference between Shafthead & 6" Riser, w.g.
1430	2.00"	407.65" w.g.			1.84"
			1	0.060" w.g.	
1500	2.02"	407.59			1.82"
			2	0.190	
1530	1.95"	407.40			-
			3	0.275	
1606	1.74"	407.07			1.13
			-	0.063	
1625	1.67	407. 03			1.18

The increased rate of shafthead pressure drop with two and three compressors working may have resulted from decrease of flow from workings to shaft, but if so it is difficult to reconcile the rate of pressure drop during the period 1430-1500 hours with that of 1606 - 1625 hours, since the pressure differential at shafthead and bottom seal had not altered in the same ratio.

It seems possible that during the 3 compressor stage, gas was being drawn from the shaft into the workings. If this happened, loss of gas from the shaft would represent leakage plus flow into main heading, and the leakage rate would have had a proportional value of <u>less</u> than 550 c.f./h. at 0.45" w.g.

During the respective compression stages 260, 660 and 1,250 cubic feet of gas were lost from the shafts, based on the observed drop in absolute pressure.

(c) Flow values during the compression stages were -

Time Hours	Compressors working	Flow rate, c.f./h. Initial	Flow rate, c.f./h. Final	6" Riser Absolute Pressure " w.g.	6" Riser, " w.g.	Vacuum at Compressor " w.g.
1429	-	-	-	409.49	3.84	-
1430		3,500	-	408.56	2.91	-
	1					
1500		-	3,200	408.47	2.90	-
1500		6,700	-	406.25	0.68	?
	2					
1530		-	6,000	406.20	0.75	1.5
1530		9,000	-	-	-	13.5
	3					
1604		-	8,400	-	-	22.25
1606	-	-	-	408.18	2.85	-
1625	-	-	-	408.21	2.85	-

The increase in pressure drop necessary to increase the flow from 6,000 to 9,000 c.f./h. cannot be reconciled with increased resistance in the 6" pipe resulting from the higher flow, and another anomaly is shown by the increase of 8.75" w.g. vacuum accompanying reduction in flow from 9,000 to 8,400 c.f./h.

The immediate rise in absolute pressure following upon the termination of pumping to a value exceeding that of shaft pressure proves that no vacuum existed in the workings as a whole during the 3 - compressor stage. A partial vacuum may have occurred in the zone adjacent to the end of the 6 - inch pipe, behind the main seal, but this requires postulation of an almost complete blockage in the headings at no great distance from the Doncast shaft. If this intermediate zone was under vacuum, gas may have been drawn from the shaft into this zone during the 3 - compressor stage.

Alternatively, it is possible that water is standing in the pipe leading from the 6" Riser to the bottom seal, and that with high gas flow rates this water is drawn up into a rising limb of the pipe, giving a constantly increasing head.

On cessation of gas flow the water falls to its original level and the full head of gas is restored in the 6" Riser.

The gas flow values shown have apparently been read direct from the Bailey meter chart; they may be subject to correction for temperature, pressure and gravity, with a net reduction of 10 to 15 per cent.

(d) Although barometric pressure rose only 0.03" w.g. absolute during the period 126 - 145 minutes, the 6" Riser water gauge gave a fairly constant reading of 2.85" throughout. Since pressure in the workings rose only from 432.84 to 432.87" w.g. absolute, whereas during the period 9 - 29 minutes it had risen more rapidly to 434.31" w.g. absolute despite the higher leakage rate then prevailing, it is apparent that some new factor had been introduced.

Since under static conditions the temperature of the gas is 63°F. below the top seal and 95°F. in the workings, it appears likely that the value of H. will vary when hot gas from the workings fills the 6" Riser. During the pumping period, gas expands slightly in the 6" Riser and must take up heat; upon cessation of pumping, pressure is largely restored in the 6" Riser and the gas gives off most of its added heat, leaving it with approximately the same temperature that it had in the workings.

Higher average temperature of gas in the 6" Riser would give lower average density and consequently a lower value of H, which would be reflected in a higher water gauge reading at surface for a given absolute pressure in the workings. Temperature within the 6" Riser would gradually return to normal with relative increase in average density and, in consequence, a higher value for H which would be reflected in a lower water gauge reading.

The relative values of H are -

Gas Temperature near top of 6" Riser.	Absolute Pressure at 6" Riser.	H.
63°F	408.18 w.g.	24.66" w.g.
90°	408.18	24.04
	Difference	0.62" w.g.

Accordingly, it appears that during the period 126 - 145 minutes, absolute pressure in the workings in creased while the value of H increased, with very little resultant change in the value of 6" Riser water gauge reading. To obtain true values of H after flow, accurate gas temperatures must be recorded, preferably close to or below the 6" Riser valve.

It is quite likely that the 6" Riser pressure curves for the tests of 9th and 10th January have also been influenced by subnormal values of H after flow.

14. Possibility of Increasing the Gas Yield by the Application of Vacuum.

In (6) above, a hypothetical case has been made out for the use of vacuum to obtain higher yields of gas. Without accurate data on which to base calculations, it is possibly unsafe to give theoretical yields which might encourage the Natural Gas and Oil Corporation to risk the loss of further capital. On the other hand, if any possibility exists of turning a present loss into a future gain, that possibility should be fully explored.

The measured flow rates in August, 1944 are shown in (6) above, as ranging from 1,610 to 2,270 cubic feet per hour. If an assumption is made that these yields were at abnormally high and low barometric pressures respectively, the worst possible conditions will have been adopted as a basis for calculating yield with vacuum.

From Darcy's law, the ratio of two rates of flow in the same system at a given time may be shown -

$$\frac{Q_{12}}{Q_{13}} = \frac{(P_1^2 - P_2^2)}{(P_1^2 - P_3^2)}$$

Let Q_{12} = 1,610 c.f./h.

Q_{13} = 2,270 c.f./h.

P_2 = 16.74 pounds per sq. inch abs. (Barometric reading 30.8")

P_3 = 15.73 P.S.I.A. (Barometric reading 29.1")

(Relative values of H, with air in shaft, are 44.60 and 39.73" w.g.)

Whence P_1 = 18.98 pounds per sq. inch absolute

The petroleum industry commonly uses vacua ranging from 15 to 28 inches of mercury for the recovery of gas from depleted fields, with 21.5" as a general average. However, it must be recognised that production of gas from a depleted field is the final stage of operations, all plant and equipment, with the exception of pumps, having been installed and the cost recovered during the period of flush production.

Taking the average value of vacuum, which is the equivalent to a reduction of 10.55 P.S.I.A., the factors of the equation become -

Q_{12} = 1,610 c.f./h.

Q_{14} = to be determined

P_1 = 18.98 P.S.I.A.

P_2 = 16.74 "

P_4 = 6.19 "

Whence Q_{14} = 6,470 cubic feet per hour, which is the probable minimum yield obtainable by the application of 21.5" Hg. vacuum in 1944.

Taking the values for pressure from (7) above, a more favourable result is available; the factors which change are -

P_1 = 17.28 P.S.I.A.

P_2 = 16.58 "

P_4 = 6.03 "

Whence Q_{14} = 17,800 c.f./h.

It may be possible to secure from the Sydney Weather Bureau average barometric pressures for the 15th and 23rd. August, 1944, which would afford a closer estimate than is possible using assumed values. A further step might be taken towards accurate assessment of yield, by securing the colliery inspectors' records of air-stream analyses and the barometric records of the years. From this data the original gas pressure could be calculated with reasonable accuracy, and, what is more important, a production decline curve could be plotted which would indicate the probable life of the colliery under commercial recovery of gas.

15. Sealing the Shafts.

It is obvious that until the shafts have been sealed off, there will be no possibility of working under subatmospheric conditions. All attempts to seal the workings and shafts have proved abortive, but as these attempts were based on lack of appreciation of the engineering features involved, the problem may not be insoluble.

In the petroleum industry a gas field is tapped by boring a hole into the reservoir rock, inserting casing, and cementing the casing securely in place. It is apparent that boring a hole into the workings at Balmain would not solve the problem, the shafts would remain as channels for air.

The following notes indicate the problems which need consideration when planning to seal the shafts, and embody suggestions for carrying out the work -

(a) Water:-

The water pump at the 800' level has been idle since coal-mining ceased, and water has been falling freely down the shaft and trickling down the walls. The fitter making the pipe connection at the foot of the 6 - inch Riser reported that his work was hindered by water coming down the shaft, and there is another report to the effect that water could be heard trickling into the headings.

The headings are not all on the same level; thus in 1943 the water was only 18 inches deep in the main heading opposite the engine-room cut-through; it was progressively deeper along the cut-through, and up to the roof in the stable drive. To get through this latter section to the back heading (leading to the upcast shaft) the roof had to be brushed.

When attempting to put a seal in the back heading, the contractor had to work in 5 feet of water; deep water was also found in the empty truck drive.

The mine was reported to be dry, therefore this water could only have come from the shaft. Apparently the water has collected and risen to the level of the coal seam, and a report states that it is now seeping away through the coal. No rise in water level was observed during 1943-44.

The possibility that the water level would rise if vacuum were applied to the workings must be borne in mind. If the coal is gassy, and references to gas bubbling up through the water tend to show that it is, then a gas pressure may exist ahead of the water, and this pressure may be sufficient to drive the water back in the event of pressure being reduced in the headings.

While it is unlikely that the reduction in shaft pressure following upon the construction of top seals would have brought water back into the headings, it is highly probable that water would not get away as rapidly as it did before the top seals were placed, and it follows that water may now be standing higher in the shaft and headings than it did in 1944.

Since the behaviour of the water cannot be foreseen, it is apparent that any attempt to seal the workings must be based upon the removal of all water now standing in the shaft and headings, the repair of water-rings and recommencement of pumping from the 800' level, and provision for keeping the headings dry in future.

However, the position with regard to water is not quite clear. Reference is made later in this report to the possibility of water travelling along the headings; it is quite likely that water is not, and never has been, seeping into the coal.

(b) Rock Falls:-

Access to the stoppings put in when the mine was abandoned was hindered in 1943 by blocked headings, and falls up to 15 tons in weight occurred while the men were working. No.2 seal was built into an apparently solid roof, but a few months later the roof was found to be fractured, and had to be scaled upwards a distance of 15 feet before reaching solid ground.

The timbering and steel supports used in the headings and engine room indicate that the strata penetrated were incompetent. As long as the timber remained in good condition, there would be no release of pressure in the rock face. With the disintegration or collapse of the timber, pressure would be released and local falls would occur. The new roof would stand for awhile, possibly for months; but progressive falls would occur until all head room became filled, when the broken ground would support the roof. Although no further falls would occur, the roof would fracture, swell, and consolidate the broken ground below.

The height from the floor of the original heading, through broken ground to the top of the shatter zone, cannot be estimated within close limits; it might eventually be 100 feet, it would be unlikely to exceed 250 feet.

It is apparent that seals placed with a view to permanency should be located in the shaft well above any possible extension of the shatter zone.

(c) Recovery of Casing:-

Presumably gas would be withdrawn from immediately below the seals, and as the existing 6 - inch and 8 - inch casings would not be required they might be removed and sold.

With the lowering of water level, gas will flow freely past the seals in the main and back headings. (These seals were constructed in water, and, on the assumption that a head of water would balance any likely pressure, no attempt was made to clean out broken rock lying on the floor of the headings, or to scale-off shatter rock in the walls below water level).

Air should be pumped down the 6 - inch Riser and the 6 - inch pipe leading to the main seal should be cut alongside the concrete block; a second cut should be made and a section lifted out to allow a cap to be fitted over the 6 - inch pipe to prevent gas from coming back where men are working. The 6 - inch and 8 - inch casings should then be cut immediately above the concrete block, and withdrawn.

(d) Repairing Bottom Section of Downcast Shaft:-

In 1942, the lower section of brickwork in the downcast shaft was found to have collapsed, and was replaced with concrete.

It would be necessary to inspect all the brickwork in the Downcast shaft, and that in the Upcast shaft from the surface to the seal location, and renew any sections which are damaged. Since the headings must be kept free from water, the deep-well tubing and rods must be safe-guarded from damage by falling masonry or rock. Also there must be no risk of fall on to the seals.

Consideration will also have to be given to supporting the brickwork in the zone above the seals which is to be filled with water; the brickwork here must be strong enough to prevent collapse, but sufficiently open for water to pass through. The water acts as a buffer between gas and air; under ideal conditions only a few inches would be required, but in this case it would be necessary to provide sufficient head to drive the water into every opening.

(e) Location and Construction of Seals:-

The possibility of constructing seals which will bond with the shaft walls and make an air-tight joint is held to be remote. It would be necessary to provide a sealing medium, such as a head of water above the seal, to ensure that neither air nor gas could pass.

When choosing a site for the seal, cores of rock should be taken and tested for permeability to air under a pressure of 25 pounds per square inch.

The seals should be made of reinforced concrete, suitably arched, and designed to carry a 150' head of water with a safety factor of 10.

High-gelling mud should be filled in above the seal, to a depth of about 30 feet. The purpose of this mud is to prevent leakage of water through any defect in the seal, or between the seal and the rock. Water should then be filled in to give a total head of about 150 feet above the seal.

Since provision would have to be made for keeping the water at a fairly constant level, which might mean the addition or removal of water from time to time, a site about 200' below the 800' water flow would probably be satisfactory. Alternatively, the seal could be constructed 150 feet below the surface, where freedom from salt water indicates that the strata are impermeable. In this case it would be desirable to instal a pipe of adequate capacity to carry the water from the water-rings at the 800' flow to the shaft sump, whence it would be removed by the deep-well pump, and thus prevent further damage to the shaft brickwork.

There would be some advantage in having the seals near the surface: only one pump would be necessary (in the Downcast shaft sump) as water could stand between the seal and surface in each shaft; seal construction would be simplified, and air could be provided more readily to ensure safe working conditions.

(f) Safety:-

The problem of de-gassing the shafts so that workmen can descend to instal pumps, repair water-rings, repair brickwork, withdraw casings, etc., is one for the State Mines Department and the Company's technical advisers.

Both seals should be constructed with pipe nipples bedded into the apex, and with 12 - inch pipe extending back to and securely anchored at surface. Full-opening gate valves to be fitted at surface.

During the intial stages of seal construction in the Downcast shaft natural draft wouldpresumably ensure safety of operation; prior to constructing the apex of the seal, the pipe to surface should be installed and connected to an air-pump having sufficient capacity to keep the gas content of the return air within the limits prescribed by safety, with an assumed gas yield of 4,000 cubic feet per hour. Air pumping would continue until the Upcast shaft seal is placed.

After the mud and water have been placed in the shafts, the pipe from one seal would be connected to a gauge, to give readings of pressure or vacuum conditions under gas recovery while the other pipe would be connected to the gas pump. Provision should be made for running a dipper on a piano wire, using a packed gland and a container, so that periodic tests may be made of water level at shaft base with a view to keeping the operation of the deep-well pump to a minimum.

The projected work is confined to the shafts. Provided that ventilation can be restored, the work may be carried through in complete safety, all defective sections of the shaft being repaired or shored-up before the men proceed deeper. The work programme should be carefully planned, with safety of personnel as the ruling factor.

While horizontal drilling into the coal seam would undoubtedly improve the yield of gas, the cost of repairing the main heading to give access to the coal face would be prohibitive, nor could this work be carried out without serious risk to personnel.

Non-sparking tools should be used on all underground work.

(h) Dip of Coal Seam:-

According to the Shaft Log, the coal seam dips 1 in 40 N. 75° E. Since the main heading follows the coal and runs almost due east, it must have a downward slope. If this is correct, water must be progressively deeper along the main heading than it is near the Downcast shaft.

It follows that the reported loss of water by seepage into the coal may not have occurred. The water may be running away down the heading, may even have reached the workings.

Since this aspect has not been touched upon by any earlier writer, it is possible that evidence may have been obtained of a change of dip in the coal seam not far from the shaft.

If no such change occurred, the whole question of recovering gas from the colliery would have to be reconsidered in the light of a possible water blockage in the headings at a point where the strata were locally competent. In the absence of falls and roof shattering, such a blockage might effectively seal off all gas in the workings.

16. <u>Summary.</u>

The Balmain Colliery was very gassy, yielding up to one million cubic feet per day during the mining period. Coal was never produced at a profit.

The production of gas for disposal as motor fuel during the war was not commercially successful. A proposal to utilize the methane as a substitute for gas oil in the enrichment of town gas was rejected on the grounds that the quantity available did not warrant the capital expenditure on exploitation.

Leakage of gas at shafthead was known, and was believed to be responsible for the low commercial recovery of gas. Tests were accordingly made by the Bureau of Mineral Resources, Geology and Geophysics in February, 1947 to determine, if possible, the rate of leakage and the optimum yield of gas which would be available if all leaks were stopped.

While the tests gave additional information relating to the behaviour of gas in the mine, they did not provide all the data necessary for accurate assessment of the gas production rate.

On the basis of these tests, and previous tests made by Australian Gas Light Company Limited, a case has been made out in general terms as follows:-

(a) The gas yield has fallen from 1,000,000 cubic feet per day in 1911, to about 60,000 cubic feet per day in 1944. This drop in production is normal, and the colliery may now be considered to be a depleted gas field.

(b) The rate of production decline now approaches zero and the mine will continue producing gas at slightly below the present rate indefinitely.

(c) The mechanics of gas flow within the coal are complex, with three principal factors:- permeability of coal, pressure available to displace gas towards the workings, and adsorptive power of coal in relation to gas. The original gas pressure was low leading to a rapid decline in gas production when mining operations ceased. No information is available on the other factors.

(d) The effective volumetric capacity of the Shafts is 1.5×10^6 cubic feet, while that of the Workings is between 2 and 3×10^6 cubic feet. The shafts are separated from the Workings by an imperfect seal, while an adjacent permeable stratum facilitates gas flow.

(e) Leakage at surface and flow through or past the bottom seal conforms to Darcy's law for the linear flow of gas through permeable strata. The leakage rate in February, 1947, was between 300 and 700 cubic feet per hour at minimum permissible shafthead/atmospheric pressure differential, and probably nearer the lower limit.

(f) The gas yield in February, 1947, was between 2,500 and 3,000 cubic feet per hour, when the Workings pressure was 435" water gauge absolute with the shafts full of gas.

(g) The gas yield varied with barometric pressure during the mining period but the extent of variation is unknown; it varied in 1944, when yields approximately 1,600 to 2,300 cubic feet per hour were obtained, with the Workings subject to atmospheric pressure plus a head of air in the shafts; it still varies, and reduction of Workings pressure by the application of vacuum will accordingly given an increased yield of gas.

(h) The gas yield resulting from application of vacuum of the order of 21.5 inches of mercury cannot be calculated with such data as are at present available. If this vacuum had been applied in 1944, the gas yield would have had an estimated minimum value of 7,000 cubic feet per hour. The present minimum yield would have a lower value.

(i) Inspection of mine records may yield data which will permit reasonably close assessment of potential gas yield, thus enabling returns to be estimated and compared with probable production costs to show whether or not the project is commercially attractive.

(j) Problems relating to the construction of seals in the shafts have been outlined, and the necessary work can be carried out in safety.

(k) The possibility of a water lock in the headings has been recognised.

17. Recommendations

It is considered that no useful purpose would be served in making further tests of gas yield under existing conditions.

The implications of a possible water lock in the headings should be carefully examined before making any plans to recover gas on a commercial basis.

An opinion should be obtained from a competent authority upon the conditions under which methane exists in coal, with particular reference to adsorption of gas and the critical pressure of adsorption.

(H. Temple Watts.)

Melbourne.

29th December, 1948.

APPENDIX.

References.

A. Australian Journal of Science, Vol. IV. No.3 December, 1941, p.p. 102-103, amplified by the present writer.

B. Report by Messrs. Phillips and Reid, 5/2/46.

C. Annual Report, N.S.W. Department of Mines, 1907, page 154.

D. Extract from log of bore sunk below the Downcast shaft:-

4177' Struck gas in soft sandstone. Cemented 6" casing at 4,170 feet. Gas pressure 16 pounds per square inch.

4546' Struck gas in shale and sandstone. Gas pressure 15 P.S.I.

4602' Struck gas in shale. Gas pressure 3 P.S.I.

Gas is logged at greater depths, but initial pressures were low.

27th Nov. 1936:	Depth 4,756'. Bore sealed down.		
28th "	Pressure	2	P.S.I.
29th "	"	4	"
2nd Dec.	"	5	"
3rd "	"	9	"
7th "	"	9½	"
24th "	Depth 4,805'. Bore sealed down		
27th "	Pressure	4	P.S.I.
28th "	"	5½	"
31st "	"	8	"
10th Jan. 1937:	"	12	"
1st Feb.	"	16	"
2nd "	"	17	"
3rd "	"	17	"
24th July,1937:	Depth 4,935'. Bore sealed down.		

1st Aug. 1937:	Pressure	12	P.S.I.
20th "	"	50	"
12th Oct.	"	52	"

(Note: Comparison of the rate of pressure rise at depth 4,805' with that at 4,935' indicates that the higher pressure gas was encountered below 4,805'.

There are gaps in the sample log; the bore was still in Coal Measures at 4,543', and in Upper Marine at 4,750'.

The rate of gas flow from the bore was variously reported, but exhaustive tests made in January-February, 1942, proved that the yield was between 200 and 400 cubic feet per day under a vacuum of about 22 inches water gauge).

E. Darcy's law for linear displacement of gas through permeable strata:-

$$Q = \frac{112\ A\ K\ (P_1^2 - P_2^2)}{n\ L\ T\ Z.}$$

where -

Q = rate of displacement, cubic feet per day.

A = area, square feet.

K = effective permeability, darcys.

P_1 and P_2 = pressures, pounds per square inch absolute.

n = viscosity of gas, centipoises.

T = temperature, ^{o}R.

L = length, feet.

Z = compressibility factor.

F. Calculation of H is in accordance with Spang - Chalfant Engineering tables -

(a) to determine the effect of temperature gradient on density of gas:

$$\frac{D_m}{D_o} = \frac{b\ T_o}{L} \log_e \left(1 + \frac{L}{b\ T_o}\right)$$

where:

D_m = average density of gas column

D_o = gas density at shafthead

L = depth of bore, feet.

b = temperature gradient, feet per degree F.

T_o = shafthead temperature in degrees F. absolute. (Taken as 63° at the zone of constant temperature, 15 feet below shafthead, at Balmain).

(b) to determine the pressure rise due to the weight of a column of gas:

$$\frac{P_2}{P_1} = \frac{e^{.0000347\ D_m\ L}}{1}$$

where:

P_2 = absolute pressure at bottom of bore.

P_1 = " " " top " "

(any pressure units may be used).

(c) $H = P_2 - P_1$

G. Density of gas at N.T.P. :

The official analysis of the Balmain gas is given by Australian Gas Light Company Limited as -

CO_2 -	3.2 %
O	0.3
N	2.2
CH_4	94.3
	100.0

The density of this composite gas has been calculated as 0.5948 at 60°F. and 29.921" Hg.

H. Spitzglass' equation for flow of low-pressure gas, from Gas Engineer's Handbook -

$$Q = 3550 \sqrt{\frac{h D^5}{G L \left(1 + \frac{3.6}{D} + 0.03D\right)}}$$

where =

Q = rate of flow, cubic feet per hour.

h = pressure drop, inches water gauge.

D = diameter of pipe, inches.

G = specific gravity of gas (air = 100)

L = length of pipe, feet.

The following additional publications refer to the Balmain Colliery:-

"Rock Temperatures at Sydney Harbour Colliery, Birthday Shaft, Balmain", by J.L.C. Rae, E.F. Pitman and Prof. T.W.E. David.
Journal of the Royal Society of New South Wales, Vol.33, 1899

"Problem of the Great Australian Artesian Basin"
Alex du Toit. Idem., Vol.Ll., 1917.