CONSIDERATIONS TO INCREASE GAS DRAINAGE RATIO BASING UPON METHANE DRAINAGE PRACTICE IN JAPAN

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ABSTRACT

Basing upon many and long practical experiences of gas drainage from coal seam and results investigations on the gas flow through in si-tu coal seam using tracer gases,it became clear that solid coal itself is hardly gas permeable or has extremely low gas permeability. Almost all of gas flows from a coal seam into boreholes through fracture networks intersecting with them.Primary and secondary fractures in coal seams differ in their size and continuity from place to place according to differences of the coal strength and the stress conditions. A lot of gas can be drained through boreholes which intersect with many and/or wide fractures.

A mathematical model for gas flow from a coal seam to a borehole through a discoidal fracture is proposed. From the numerical analyses,the apparent radius of the discoidal fracture in this model is shown to be a good indication of the gas drainage ratio.

In addition to this,an atempt to make fractures around a borehole using high velocity water jet(ca.1mm dia.,300-700atm., 100-200 l/min.) is introduced.

INTRODUCTION

Japan has produced 18-20 million tons of coal per year these several years. About half of the production comes from eight coal mines dispersed in Ishikari coal field of Hokkaido prefecture,north island of Japan. Gas drainage methods from coal seams have been used at all of these coal mines.

It is well known by experience that there is a big difference in difficulty of the gas drainage from coal seams at a Northern and a Southern part of the coal field. To compare difficulty of the gas drainage,following two ways are used. The first way is the index called "gas drainage ratio"defined as follows.

$$\text{Gas drainage ratio} = \frac{A}{A+B} \times 100\ (\%)$$

Where A: Volume of methane drained by gas drainage methods.
B: Volume of methane emitted to ventilation current.

The average gas drainage ratios of these coal mines are approximately 30% and 50% at the Northern and Southern part of the coal field respectively. The second way is to compare the distances between boreholes drilled through coal seams. These distances which have been decided by experience are less than 10m at the Northern part and about 25m in the Southern part. Under the hypothesis that methane contents of coal seams are about same at both parts,above mentioned two ways show that the gas drainage is easier at the Southern part than the Northern part of the coal field.

To find out main factors deciding the

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The Aus.I.M.M. Illawarra Branch Symposium,
"Seam Gas Drainage with particular reference to the Working Seam", May 1982

diffculty of the gas drainage, several observations and measurements were conducted.

Basing upon these results, a mathematical model for a gas flow into a borehole from a fractured in si-tu coal seam is proposed.

Traditional gas drainage technics with many boreholes in coal seams like pincushions are very expensive and giving big trouble for the management of coal mine companies.

Therefore it is very important to seek ways to increase gas flow from a borehole and ways to drain gas from coal seams which contain few cracks in them.

RESULTS OF OBSERVATIONS

1 Gas flow rate from bore holes

Fig.1 shows the typical changes of gas flow rate from boreholes at Yubarishinko coal mine in the Southern part and Sunagawa coal mine in the Northern part of the coal field.

These boreholes were drilled into a comparatively small area of the same coal seam from one boring station, therefore all borehole are thought to be about same conditions at each mine.

As shown in the figure, the gas flow rate is higher in the Southern part compared with the Northern part. In addition to this, the coefficients of variant of gas flow rates immediately after borings are 1.0 at the Northern part and 0.5 at the Southern part.

Therefore it can be said that each borehole has different gas flow characteristic in the Northern part compared with the Southern part.

2 Tracer tests

Many tracer tests were conducted using in si-tu coal seams and the systems shown in Fig.2 . Freon and radioactive methane were used for tracer gases. Distances of the two boreholes were changed from 0.5m to 1.8m. Results obtained are as follows. When the depth of these test boreholes were shallower than about 5m, the tracer gas flowed through the coal seam and could be detected, but when the depth were deeper than 5m, the tracer gas were sometimes detected and sometimes not detected.

3 Measurement of acoustic emission(AE) accompanied by a boring into a coal seam

Fig.3 shows AE events and counts resulting from borings into the coal seams of the both parts. It is clear from the figure that a lot of AE appear in the Southern part compared with the Northern part. From this result, it can be supposed that many cracks surrounding a borehole will be appeared by borings in the Southern part.

4 Results of observation by borehole-scope

Observations of inside surface of boreholes were conducted using the borehole-scope shown in Fig.4.

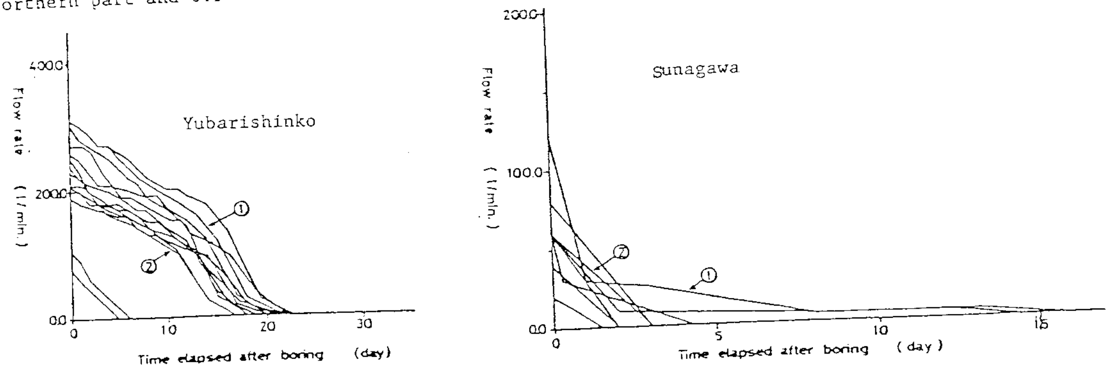

Fig.1 Difference of gas flow rate from boreholes in both parts

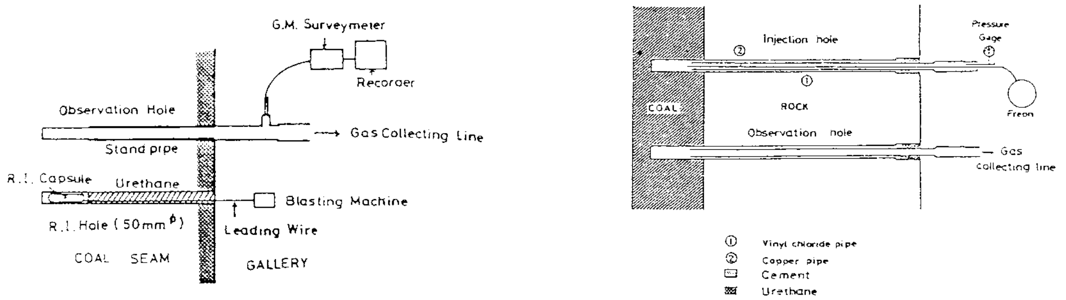

Fig. 2 Systems of tracer test

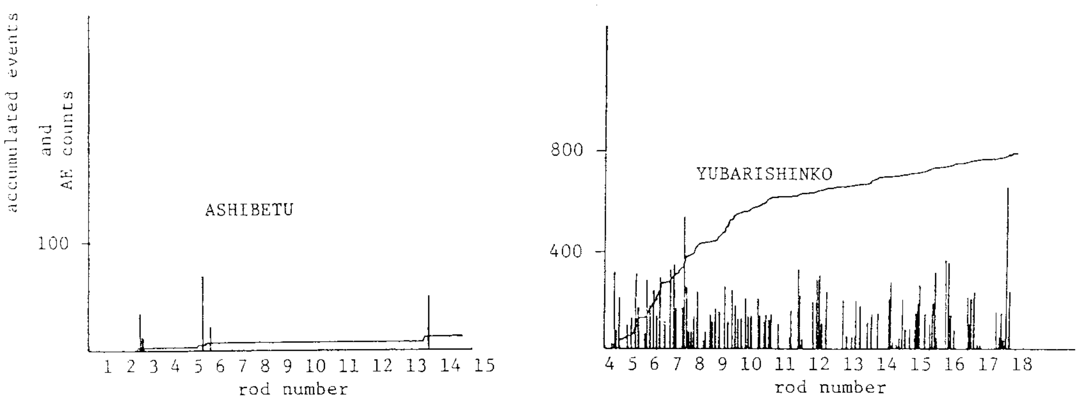

Fig.3 Results of AE mesurement (After T.Watanabe and I. Nakajima)

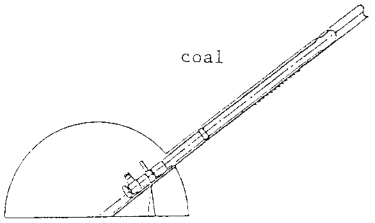

Fig. 4 Borehole-scope

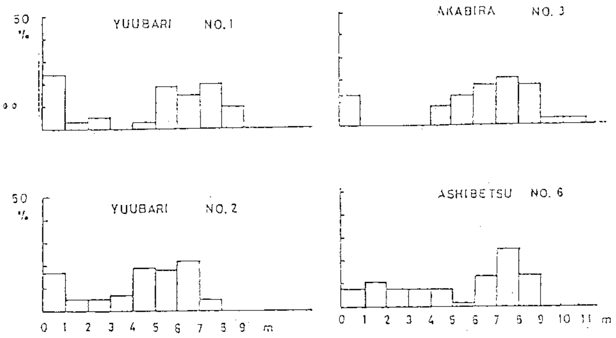

Fig.5 Frequency distribution of cracks observed.

Chemical light installed to the head of the scope gave clear sight of the inside surface of boreholes. Maximam depth of observation was 13m from the gallary. Fig.5 shows the frequency distribution of cracks observed. There are a lot of cracks from the surface of the gallary to the depth of 1m.

Cracks decrease their number at more deeper part,but from the depth of about 5m, increse their number again and attain the peak at the depth of 8-9m. In addition to this, absolute number of the cracks observed was much more in the Southern part compared with the Northern part.

DISCUSSION BASING UPON OBSERVATION

Basing upon above mentioned results of observations,to discuss about a gas flow phenomenon into a borehole from a coal seam, three stage models showm in Fig.6 are thought to be worth-while. Stage I shows the state surrounding a borehole drilled into a coal seam which contains no cracks in it. There will be made a fractured zone just arround the borehole and the width of this zone will differ from place to place by the strength of the coal and the state of stresses.

Gas permeability of this zone (K_1) should be comparatively high. There will be the stress concentrated zone at outer side of the fractured zone and the gas permeability of this zone(K_2) will be low. At outer side of this stress concentrated zone,there will be a native coal seam unaffected by the borehole.

Naming the gas permeability of this native, coal seam as (K_3),there will be the relation of $K_1 \gg K_3 > K_2$.

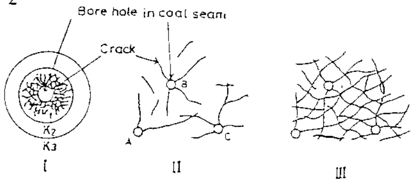

Fig. 6 Three stage model

Judging from the results of AE measurement and observations by the borehole-scope,the thickness of the fractured zone is thought to be thicker in the Southern part compared with the Northern part and this gives good explanation to the difference of gas flow rate from boreholes.

In other words,when boreholes of same diameter are drilled in the both parts, effective diameter of a borehole including the fractured zone is bigger in the Southern part and the borehole flows out a lot of gas compared with the Northern part.

Stage II shows the relation between the primary and /or the secondary fracture produced by mining activities and borehole drilled.

Under this stage,boreholes crossed with cracks flow out a lot of gas but boreholes which are not crossed with cracks flow out little gas. Therefore gas flow rates may differ largely from a borehole to a borehole.

Actual conditions of in si-tu coal seam are thought to be the closest to the stage II and especially this model gives good explanation to the big variance of gas flow rate of boreholes in the Northern part.

If the tracer test is conducted under this situation,the tracer can flow from the borehole A to C but cannot flow to the borehole B owing to discontinuity of the cracks. This is the fact sometimes experienced.

This model gives good explanation to the fact that the second borehole drilled near the first one in a same manner somtimes flow out more gas than the first one. In addition to this ,but for the cracks gas contained in comparatively close part of borehole cannot be drained,therefore gas outbursts may occur between close gas drainage boreholes.

Stage III shows the final state of cracks appeared in a coal seam. Density of the cracks in a coal seam is very high at this stage and a borehole has a high probability of intersecting with cracks.

Every borehole drilled in this zone will show similar gas flow characteristics and can flow out a lot of gas. The easiness of gas drainage and similarity of gas flow rate of boreholes in the Southern part are able to be explained by this model.

Table 1 shows some characteristics of the both parts. From this table it can be said that the exist nce of cracks in a coal seam is the main factor deciding the gas drainage ratio

A MATHEMATICAL MODEL FOR GAS FLOW FROM A BOREHOLE

As mentioned above, the state of cracks surrounding a borehole is thought to be close to the Stage II or III when gas drainage technics are applied at actual coal mines.

Therefore a mathematical model for gas flow from in si-tu coal seam into a borehole should contain effects of cracks intersecting with the borehole.

Though actual borehole intersects with many cracks, to simplify the problem,one discoidal crack of which area is same as the cumulative area of many cracks is considered.

As shown in Fig.7,total gas flow from a borehole can be described as the summation of the flow through the borehole itself and the flow through the discoidal crack.

The basic partial differential equation describing the gas flow can be written as Eq. (1).

$$\frac{\partial P}{\partial t} = \frac{K}{2q_n \mu} \left(\frac{\partial^2 P^2}{\partial r^2} + \frac{1}{r} \frac{\partial P^2}{\partial r} + \frac{\partial^2 P^2}{\partial z^2} \right) \quad \ldots\ldots\ldots\ldots(1)$$

Table 1 Comparison between Northarn and Southern part

	Northarn part	Southern part
Distance between boreholeS	< 10 m	~ 25 m
Gas drainage ratio (A/(A+B))	~ 30 %	~ 50 %
Gas outburst	Many	Few
Volume of cutting	Small	Large
Accoustic emition when bored	Few	Many
Gas flow rate from borehole	0 - 30 l/min.	200 l/min.
Uniaxial compressive strength of coal	3 - 8 Kg/cm^2	1 - 4 Kg/cm^2

Where P: Gas pressure in the coal seam

t: Time

K: Gas permeability

q_n :(= ω_n/ γ_n)

ω_n :Methane weight which can be held in unit volume of coal under normal gas pressure (P_n)

γ_n :Specific weight of methane under normal gas pressure(P_n)

μ :Viscosity of methane

r :Distance to radial direction

z :Distance to the direction of the borehole axis.

For the simplification of the calculation, hypothesis of Eq.(2) and α=1 are used.

$$\omega / \omega_n = (P / P_n)^{\alpha} \quad \ldots\ldots (2)$$

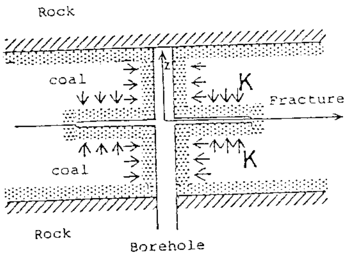

Fig. 7 Mathematical model

Initial and boundary conditions applied are as follows.

$$t=0 \qquad P = P_1 (r_0 < r \leqq r_2 \ , \ 0 < |z| < z_1)$$

$$P = P_0 (r = r_0 , \ | z | \leqq z_1)$$

$$P = P_0 (r_0 \leqq r \leqq r_1 , \ z=0)$$

$$t > 0 \qquad P_{r=r_0 , |z| \leqq z_1} = P_0$$

$$P_{r \leqq r_1 , z=0} = P_0$$

$$\frac{\partial P}{\partial z} = 0 \ (\ z = 0, \ r_1 \leqq r \leqq r_2)$$
$$(\ z = z_1 , \ r_0 < r \leqq r_2)$$

$$\frac{\partial P}{\partial r} = 0 \ (\ |z| = z_1 , \ r = r_2 \ )$$

Where, r_0: Radius of the borehole

r_1: Apparent radius of the discoidal crack

r_2: Radius of unaffected zone by the borehole

z_1: Half height of the coal seam

P_1: Initial gas pressure in the coal seam

Change of gas pressure in a coal seam can be obtained by solving the Eq.(1) numerically and then gas flow rate Q through the borehole in the model can be obtained by Eq.(3).

$$Q = \frac{2\pi\ q_n}{P_n} \int_{z_0}^{z1} \int_{r_0}^{r2} (P_1 - P) r \quad dr \quad dz \quad \ldots(3)$$

RESULT OF CALCULATION AND DISCUSSION

Typical results of calculation are shown in Fig.8 to Fig.10 . In these figures, dotted lines 1 and 2 correspond to the measured curves shown in Fig.1. In these calculations,gas permeability of the coal seam were thought to be the order of $10^{-4} - 10^{-6}$ darcy basing upon our other measurement. From the comparison of the measured and the calculated flow rate curves following discussions are possible.

From Fig.8 and 9 related to the Southern part,it is clear that the calculated cumulative gas flow curve using constants of $q_n=0.2$,$K=10^{-6}$ darcy and $r_1=15$m falls between the measured curves 1 and 2.

From Fig.10 related with the Northern part ,it can be said that the measured curve 1 agrees with the calculated curve using $q_n=0.1$, $K=5\times10^{-6}$darcy,$r_1=5$m,$r_2=20$m and curve 2 agrees with the calculated curve using $K=1\times10^{-4}$darcy, $r_1=1$m,$r_2=20$m .

As for the conclusion,the apparent area of the crack considered is 10-225 times bigger in the Southern part compared with the Northern part. This concept gives good understanding for the difference of gas drainage ratio of the both parts . These calculation results suggest that to make cracks in a coal seam is the best way to improve gas drainage ratio.

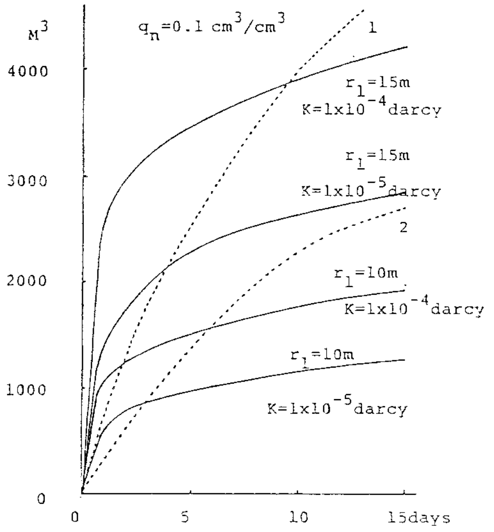

Fig.8 Calculated and measured cumulative gas flow curve(Southern part)

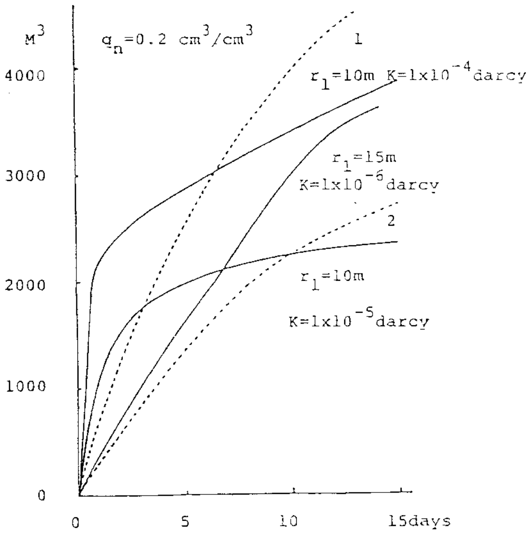

Fig.9 Calculated and measured cumulative gas flow curve (Southern part)

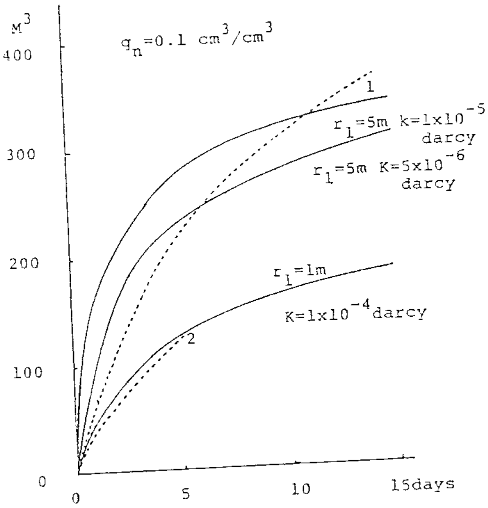

Fig.10 Calculated and measured cumulative gas flow curve(Northern part)

AN ATTEMPT TO MAKE FRACTURES AROUND A BOREHOLE

It is known by experence that gas flow rate from a borehole increases proportionally with 2-3 power of the diameter of the borehole.

In such a sence,to increase gas dranage ratio,diameter of a borehole is the bigger the better.

But drilling speed decreases with the bigness of the diameter. To overcome this problem,as shown in Fig.11,an attempt to make splittings around a borehole using high velocity water jet has been tested. In this method,after the traditional drilling (say 60-90mm dia.),a high velocity water jet(ca.1mm dia.,300-700 atm, 100-200 l/min.) is thrown to the inside surface of the borehole. By pushing or drawing and rotating boring rods,to make spiral splittings in the coal seam is possible.

Basic experiment using fixed coal sample and the jet showed that this water jet could penetrate to the depth of 30 cm.

In Japan,drillings of large diameter borehole (250mm dia.) to prevent gas outbursts have been used at a few coal mine.

But low drilling speed of this method is hindering to adopt this method at all coal mines. This water jet method has probability to improve this problem.

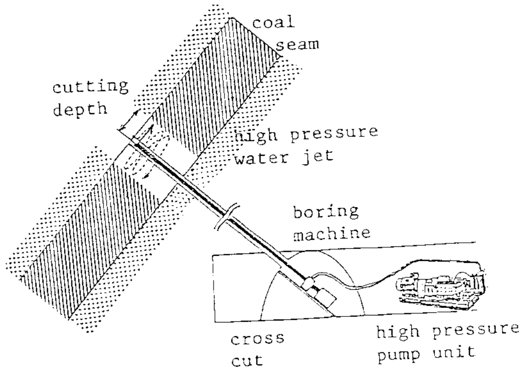

Fig.11 An attempt to make fractures using high-velocity water jet

CONCLUSION

Solid coal seams without cracks are hardly gas permeable. There are localities in density and continuity of the cracks in si-tu coal seam.

This locality decides the easiness or the difficulty of gas drainage. Borehole can flow out little gas and the effectiveness of the borehole to prevent gas outburst is restricted at where the coal seam contains few cracks.

To make fractures in coal seams by ways of some sort is basic method to improve gas drainage ratio.

For one example to make fractures in a coal seam,an attempt by high velocity water jet was introduced.

DISCUSSION

I. GRAY (A.C.I.R.L.): How successful is this new Japanese move into the hydraulic borehole mining? Will it cut solid coal or just the softer zones, possibly associated with faults? Probably much of the coal in the north is soft enough to cut anyway. Is that correct? How successful has it been? What equipment is being used? Is hydraulic mining equipment being used at Sunagawa, taking a bleed off? Are they Japanese pumps and what sort of capacity-flows do they have?

K. HIGUCHI (Hokkaido University, Japan): The hydraulic mining instrument at Sunagawa Colliery is very low pressure compared with the University of Hokkaido instrument. This water jet needs more than 400 atmos of water and rather a small volume of water. The water jet is only 1 mm diameter and on the basic experiment using lump coal that water jet can migrate 30 cm into the lump coal. When that nozzle is turned in the borehole, a discoidal fracture of up to 60 cm diameter can be possible.

R. LAMA (Kembla Coal and Coke): Continuing this question of using hydraulic jets to increase fractures around a hole, if the fractures can only be increased to 30 cm, could it be assumed that the effect of that fracture would be enough to connect further fractures outside the zone of 30 cm and create an effective zone of influence of the borehole going up to several metres? Was this method tried in the field and are there any results? What increase in flow rates over the life of the hole could be obtained?

K. HIGUCHI: Is the question about results of flow measurements using this water jet method?

R. LAMA: Yes.

K. HIGUCHI: This only the concept. The basic result, experiment started but just on the surface now. So there are no results of underground, not yet.

R. LAMA: Is it expected that increasing the fracture zones up to 30 cm could result in increasing the sphere of influence of the hole, or radius of influence of the hole and effective radius of influence of the hole going up to several metres?

K. HIGUCHI: It is expected that gas flow will increase. The big borehole 250 mm diameter drilled using a spiral bit, can drain a lot of gas, so when the water jet method is used and makes a fracture in the seam maybe about the same results will be expected.

J. SHEPHERD (A.C.I.R.L.): Is the borehole scope a prototype and is it a fibrescope, and secondly how is the very sharp increase in fracture density about 8 or 9 m up some of these holes accounted for? Look at Figure 5.

K. HIGUCHI: That borehole scope is a lens system and not a fibrescope. So it is very heavy and not such a good instrument at this time. The main reason to increase fracture at the depth of 5 m to 9 m should be from abutment pressure.

A.J. HARGRAVES (B.H.P.Steel Division Collieries): Are all four examples shown in Figure 5 shot-fired headings or are some headings machined?

K. HIGUCHI: All are shot-fired.

C. JEGER-MADIOT: According to Figures 8 and 10 of the paper, the flowrate is greater when the radius of the affected zone is bigger, even if the permeability is lower. How is the radius of the affected zone measured and how is permeability measured?

K. HIGUCHI: The gas permeability was measured using lump coal under a triaxial state of stress. Even though the triaxial state was used when that lump coal contains fracture the result will have a very wide variance. The lump coal sample was made smaller and smaller, the smaller the coal sample the lower the gas permeability was found. Lump coal contains some cracks and when the sample is cut or broken the sample smaller part contains less cracks. So gas permeability will proceed to the absolute barrier when the coal samples are made smaller. There is no information about the radius of the fracture zone.

C. JEGER-MADIOT : Measured gas flow was given for effective radius of 5 m and 1 m; how was the real value of this radius determined?

K. HIGUCHI: The dotted lines are the actual measured ones. The actual radius is not understood. A comparison was given between the calculated curve and the measured one. Perhaps measurement of the real radius is impossible.

C. JEGER-MADIOT: Certainly the effective value of radius is not the real drilled radius, but an equivalent radius taking into account the effects of the fractured zone around the borehole. Extended study with the CERCHAR computer model shows the effects of the radius on the flowrate and on the degasification. These effects depend on:

- whether the seam is permeable everywhere or only on a limited area (for example above or under a panel soon mined in another seam)
- whether the degassing borehole crosses the seam perpendicularly or is an in-seam drilled borehole (in a quite thin seam), and for the latter case whether the seam is thin or thick.

According to the results of calculation, if the seam is permeable everywhere, there is a big flow of gas, but the content of gas decreases very slowly (except in the immediate vicinity of the borehole). When there is a quite high gradient of pressure corresponding to this big flow, the gas "rushes for the door" and a bigger surface of outside, i.e. a bigger radius, permits a higher flow. When the seam is permeable only on a limited area, the content of gas decreases in time (in Fig. 1, curves 1, 2 correspond to a 35 m wide destressed area); the flow of gas is also decreasing, slowly but surely, and becomes lower than in an everywhere permeable seam. The gradient of pressure near the surface of borehole is low. After a certain time, the gas does not rush for the door; the radius of the borehole has not a sensible effect (curves 1 and 2). Nevertheless this unsensibility is higher for a borehole drilled in a thin seam than for a perpendicular borehole crossing the seam, because, for the same surface of borehole, the flow is much lower for the former than for the latter.

But obviously, the itensity of this phenomenon depends on the characteristics of the seam (content, isotherm, permeability) and on the amplitude of the differences of the considered radius.

K. NOACK (Westfalische Berggerwerkschaftskasse): In the Figures 8, 9 and 10 the constants q_n are given with values of 0.1 and 0.2 respectively. If q_n is the quantity of gas which coal can hold under normal pressure, that means 1 bar. But if this is so these figures are very low, because W. German results are about 1 to 2 cubic metres per tonne or even more and there appears to be a difference of 1 order between the figures and German figures. Is this so?

K. HIGUCHI: The value was from results of experiments using Japanese coal. Is the German figure bigger than the Japanese figure?

K. NOACK: Yes, ten times.

K. HIGUCHI: Maybe it is due to a different kind of coal.

R. WILLIAMS (Collinsville Coal Co.): This paper presents considerable investigations to study the variation in permeability between the northern and southern parts of the Ishikari coal field. It was determined that fracture density is the most important parameter in gas drainage and a mathematical model has been developed in which the calculated and field results compare quite favourably. The problem of low permeability has been tackled by using a high pressure water jet. Much of the work that has gone on in Japan appears to be of considerable relevance to research here in Australia.

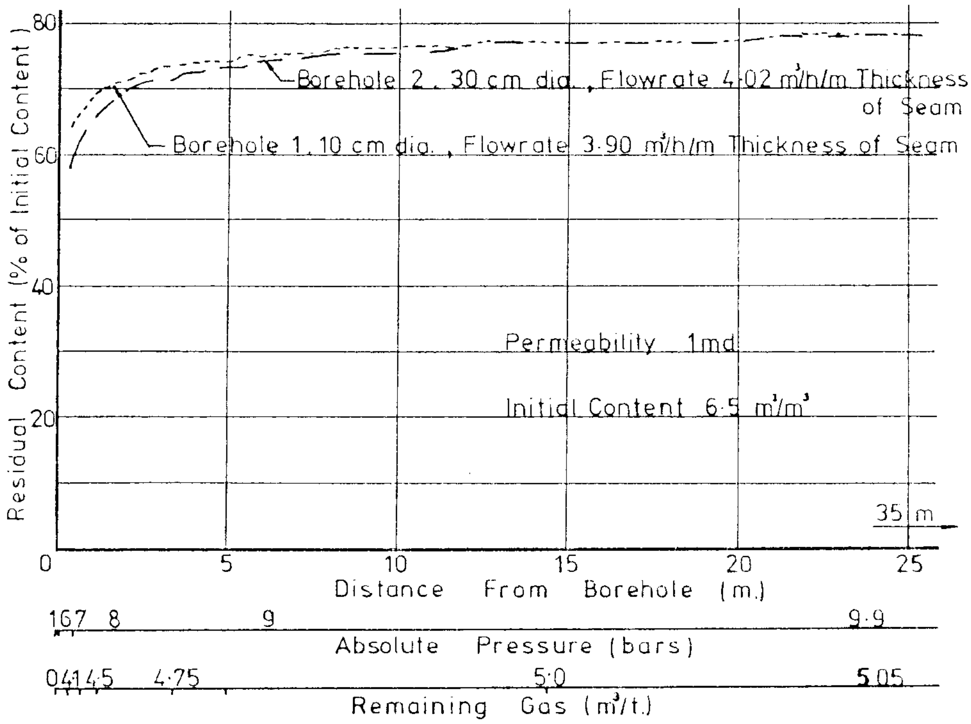

Fig. 1. Residual content and flowrate after 1 month degassing (radius of the zone to be degasified: 35 m)