A PRELIMINARY STUDY OF GAS BURSTS

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ABSTRACT. After showing data describing several of the large bursts in China it is concluded that the driving force of the gas bursts is determined by the internal energy of gas contained in the coal and a large portion of this gas must have come from the coal seam surrounding the cavity.

The authors consider the pulverization of the coal as a key factor in analysing the seepage through it. The release of gas from spheric particles of powdered coal is first dealt with and a plane one-dimensional model is studied numerically together with a similarity solution based on further simplifying assumptions. An improved estimate of available energy, taking into consideration pulverization and desorption, is given. Calculated results are in fair agreement with experiments and the estimated flow rate based on similarity solution agree qualitatively with field measurements.

It is premised that a criterion related to the minimum amount of coal being thrown out must be fulfilled in an actual burst in addition to the liability indices of the tectonic pressure, gas pressure and the gas release rate.

INTRODUCTION

Gas bursts pose a serious threat in underground coal mining in China.

Although the problem of gas bursts has been studied for many years and in many countries, due to its complexity, many points still need to be clarified. While practical engineering methods have been devised to prevent, mitigate or forecast gas bursts, they and the theories upon which they are built have not been developed to a stage where they are sufficiently reliable or quantitative.

In this paper, after showing data describing several of the large bursts in China, we shall investigate the seepage of gas through a coal bearing formation in an attempt to identify in a rational way some of the major parameters that play important roles in gas bursts.

DESCRIPTION OF COAL BURSTS

It is commonly accepted that coal bursts are a result of combined action of tectonic pressure, gas (methane and sometimes carbon dioxide) pressure in the coal seam as well as geological formation and mechanical properties of the coal. Underground coal mines are prone to bursts when the tectonic and gas pressures are high, the geological formation (folding, fissure,soft layers, etc.) complex and strength of the coal low.

According to many investigators, the evolution of coal bursts often undergoes the following stages [1].

(1) An incubation period when normal discharge of gas is obstructed leading to an accumulation of freed gas in certain regions.

(2) Initiation stage-local crushing of coal and desorption of large quantity of adsorbed gas.

(3) Extension of breakage and desorption into the coal seam.

(4) Escape of coal and gas.

(5) Continued discharge of gas from the coal already burst and from the remaining, stabilized coal bearing layer.

Stage (1) may be long or short and stage (5) may last as long as an hour or more. Stages (2), (3) and (4) are much shorter although they may cycle before reaching stage (5).

Table 1 lists data from several major gas bursts in China [2]. This table shows,

(1) The amount of gas per unit mass of coal burst is very large as shown by the large values of ξ or ξ_s. It is far greater than the amount of gas contained in a unit mass of undisturbed coal before burst, indicating that a large portion of gas must have come through the wall of the cavity formed in the coal seam subsequent to the burst. It also implies that adsorption is an important factor in counting for the source of gas. Gas flow by slow seepage through the wall of the cavity when stabilized generally carries little power to do any significant damage.

(2) The apparent specific energy $p_0 V/M$ is quite large, even though the values given in Table 1 may be greater than are actually the case, since V may well have been overestimated.

AMOUNT OF GAS CONTAINED IN COAL

Table 2 [3] gives the results of gas content measurements of specimens taken from the respective bursts shown in Table 1.

Table 1

Depth h (m)	Thickness t (m)	Angle of inclination	gas pressure p_g ($\times 10^5$ Pa)	Intensity of burst, M (t)	Gas escaped v (10^3 m^3)	p ($\times 10^5$Pa)	V_c (m^3) (ρ_c=1.6)	R (m)	R/t	Volume Ratio ξ_s (isothermal)	Volume Ratio ξ (Adiabatic)	Energy Evolved $p_a v/M$ ($\times 10^4$j/t)	TNT Equivalent (kg/t)
230	2.5	24°	24.6	1,350	102	56.4	844	10.36	4.14	4.82–8.67	8.21–14.8	754	1.80
295	4.1	31°	18.5	2,000	1,300	72.3	1,250	9.85	2.40	56.2	91.4	6,500	15.6
520	4.0	60°	36	5,270		127.4	3,290	16.2	4.05				
330	6.0	12°	16	1,700	180	80.9	1,063	7.51	1.25	10.58	16.3	1,059	2.62
216	4.6		17.5	4,500	1,280	52.9	2,810	4.41	0.961	26	41.9	2,844	6.80
520	2–3		8.0	12,780	1,400	127.4	7.990	35.6	17.8–9.7	21.9	31.0	1,095	2.62

In this table, gas content was measured under a pressure of 30 atmospheres. The measured values were then converted into Q' corresponding to the actual gas pressure pg by the empirical rule $Q'=Q\sqrt{pg/30}$, a relation which has been found to be valid for $pg\leq 20\times 10^5$Pa. It is seen that the TNT equivalent of paQ' is large in nearly all the cases quoted in Table 1.

Table 2. also shows that gas exists mainly in the adsorbed state. The ratio of the amount of gas adsorbed to that contained as free gas in the pores of the coal is at leas 4 to 9. This means that desorption is an important factor in gas bursts.

Table 2

Gas content Q(m³/t)	Adsorbed Q_a	Free in pores Q_f	Converted to p_g, Q'	$p_a Q'$ ($\times 10^4$ j/t)	*TNT* equivalent (kg/t)	Energy ratio
14.1	13.0	1.05	12.8	128	0.305	0.0099
15.1	13.9	1.27	11.9	119	0.284	0.0060
16.6	13.4	3.16	18.2	182	0.435	0.0149
14.2	13.1	1.09	10.4	104	0.248	0.0051
22.2	20.9	1.28	16.9	169	0.405	0.0038
7.22	7.10	0.12	3.72	37.2	0.089	0.0036

STRAIN ENERGY AND INTERNAL ENERGY OF GAS

It is known from elasticity theory that to remove a sphere of volume V_c in an infinite body under a hydrostatic pressure p, the strain energy released W_1 is given by

$$W_1=\frac{8}{3}\frac{1+\nu_1}{E_1}p^2V_c \tag{1}$$

where E_1 is Young's modulus, ν_1 the Poisson's ratio. Likewise, to remove a penny shaped volume V_c of radius R and thickness D, W_1 is given approximately by

$$W_1=\frac{4}{3\pi}\frac{1-\nu^2_1}{E}\frac{R}{D}p^2V_c \tag{2}$$

On the other hand, the strain energy W_2 of coal of the same volume V_c under pressure p is given by

$$W_2=\frac{K}{2}p^2V_c \tag{3}$$

where K is the bulk compliance of coal regarded as a homogeneous elastic body. The ratio W_2/W_1 is equal to 1.5–0.15 and 2.5–0.25 respectively, depending on whether (1) or (2) is used, when $E_1=10^{10}$Pa, $K=10^{-4}-10^{-5}\times10^{-5}$/Pa, $\nu_1=1/4$ and $D/R=0.2$. We can compare W_1 or W_2 with the energy of gas contained in the same volume, namely p_cp_aQ'. For the spherical case with $p_c=1.6\,t/m^3$ numerical values of the energy ratio $W_2/\rho_cV_cp_aQ'$ are given in Table 2, corresponding to the various cases shown in Table 1. It is clear from this table that the driving force of gas burst is without doubt the internal energy of gas contained in coal rather than the strain energy of either the coal or the surrounding rock mass.

RELEASE OF GAS FROM POWDERED COAL SAMPLES

Many experiments have been done on the release of gas from powdered coal samples. Fig. 1 and Fig. 2 show typical results [4] when coal powder of a given partical size or a range of sizes are first pressurized to a certain pressure at a given temperature and then the external pressure is suddenly released.

By assuming that the particles can be regarded as spheres of radius R and that isothermal condition prevails, gas discharge can be calculated on the basis of the following equations,

$$\frac{1}{r^2}\frac{\partial}{\partial r}\left(\frac{K}{\mu}r^2\rho\frac{\partial p}{\partial r}\right)=\varepsilon\frac{\partial\rho}{\partial t}+S\frac{\partial}{\partial t}f(p), \tag{4}$$

$$\rho=\rho_a p/p_a \tag{5}$$

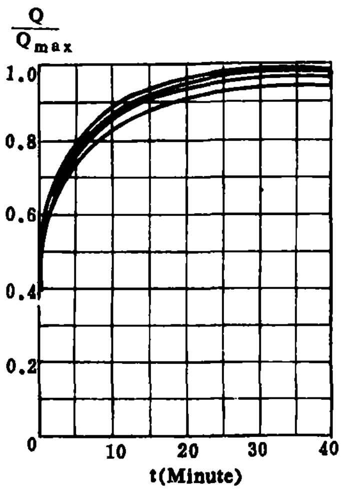


Fig. 1

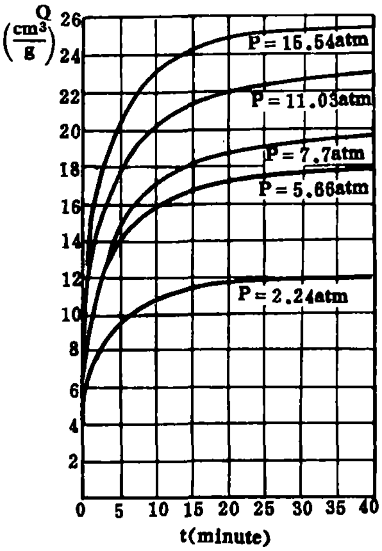


Fig. 2

The latter equation represents, of course, the ideal gas law. Here k is the coefficient of diffusion, μ the viscosity of gas, p and ρ are respectively the pressure and density, subscript a denotes atmospheric condition, ε is the porosity, S the specific adsorption surface area, and $f(p)$ the isothermal surface adsorption of gas as a function of pressure. In this paper we shall assume that Langmuir's law holds so that

$$f(p)=\frac{abp}{1+bp}, \tag{6}$$

where a and b are appropriate constants. Thus, according to (4), (5) and (6), we obtain,

$$\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2\frac{K}{\mu}\frac{\rho_a p}{p_a}\frac{\partial p}{\partial r}\right)=\left[\frac{\varepsilon\rho_a}{p_a}+\frac{Sab}{(1+bp)^2}\right]\frac{\partial p}{\partial t} \tag{7}$$

Eq. (7) has been integrated numerically under the following initial and boundary conditions,

I. C. $\quad p=p_0=\text{const.},$

B. C. $\quad r=R,\quad p=p_a;$

$$r=0,\quad \frac{\partial p}{\partial r}=0.$$

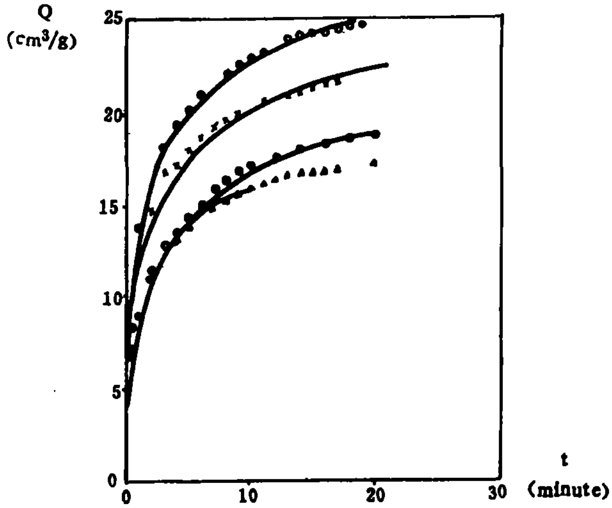
Fig. 3 shows partial results of the computation. It is seen that they fit fairly well with experimental data [8], provided material constants are properly chosen.

As shown in Fig. 3 (c), for certain samples of coal, it is possible to improve the fitting with experimental data by making K dependent on p_0 in such a way that K decreased sharply with p_0 for low values of p_0 and then gradually levels off to a constant value as p_0 increases.

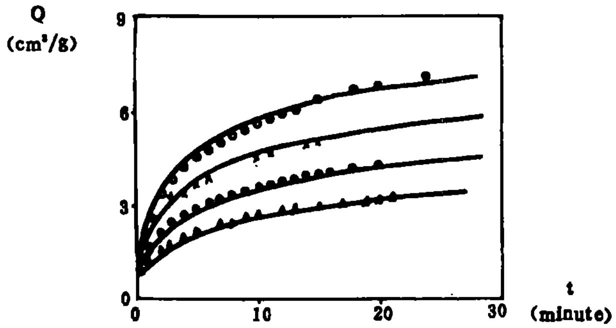
The maximum discharge Q_m of gas when the confining gas pressure is lowered from initial p_0 to the atmospheric pressure p_a is evidently given by

$$Q_m=\left[\varepsilon+\frac{Sabp_a}{\rho_a}\frac{1}{(1+bp_a)(1+bp_0)}\right]\frac{\rho_a}{p_a}(p_0-p_a) \tag{8}$$

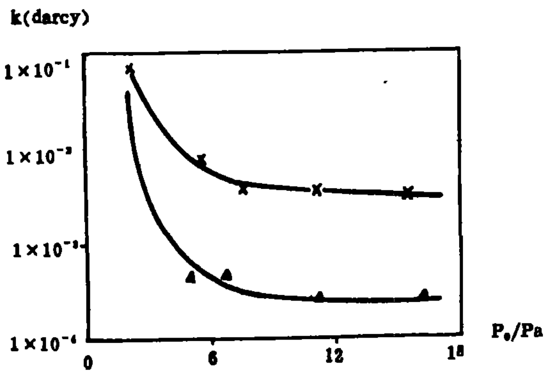
Now, based on the diffusion equation, Q_m is related to the characteristic time t_* required to complete the gas release


Q
(cm^3/g)
0
5
10
15
20
25
0
10
20
30
t
(minute)

(a)


Q
(cm^3/g)
0
3
6
9
0
10
20
30
t
(minute)

(b)


k(darcy)
1×10^{-1}
1×10^{-2}
1×10^{-3}
1×10^{-4}
0
6
12
18
P_e/Pa

(c)

Fig. 3

process in the following way

$$Q_m \frac{4\pi}{3} R^3 = 4\pi R^2_0 \frac{p_0 - p_a}{R_0} \frac{K}{\mu} \rho_a t_* \tag{9}$$

Thus dimensional argument leads to

$$Q(t) / Q_m = F(t / t_*) = F\left(\frac{3t(p_0 - p_a)K\rho_a}{R^2 Q_m \mu}\right) \tag{10}$$

with $Q_m / (p_0 - p_a)$ given by (8). Since b is of the order of 10^{-1} ($\times 10^{-5}$ / Pa) then for moderately small p_0, the dependence of $Q(t) / Q_m$ on p_0 should be small. This conclusion appears to be substantiated by experiment as shown in Fig. 2.

Next, we proceed to find an approximate solution for the case of small p such that

$$f(p) = abp. \tag{11}$$

Then

$$Q_m = (\varepsilon \frac{\rho_a}{p_a} + Sab)(p_0 - p_a) \tag{12}$$

and the right-hand side of the diffusion equation (7) becomes linear,

$$\frac{1}{r^2} \frac{\partial}{\partial r}\left(r^2 p \frac{\partial p}{\partial r}\right) = \frac{\mu}{k}\left(\varepsilon + \frac{Sa}{\rho_a} b p_a\right) \frac{\partial p}{\partial t}. \tag{13}$$

To obtain an approximate solution, we assume

$$p(r, t) = p_1(t) - \frac{A(t) r^2}{R}, \tag{14}$$

where $p_1(t)$ and $A(t)$ are unknown functions to be determined. They are related by the boundary condition

$$p_g(t) = p_1 - A(t). \tag{15}$$

Here, $P_g(t)$, pressure exterior to the sphere, is a known function of time. Substituting (14) into (13) and integrating, we obtain an ordinary differential equation for A, namely

$$\frac{dA}{dt} + \frac{15}{R^2} \frac{\frac{k}{\mu} p_g(t)}{\varepsilon + \frac{S_a}{p_a} b p_a} A = \frac{5}{2} \frac{dp_g}{dt} \tag{16}$$

the general solution of which is

$$A = -\frac{5}{2} e^{-\omega \int_0^t p_g(t') dt'} \int_0^t \frac{dp_g}{dt'} e^{\omega \int_0^{t'} p_g(t'') dt''} dt' + A_0 e^{-\omega \int_0^t p_g(t') dt'} \tag{17}$$

where $A_0 = A(0)$ and

$$\omega = \frac{15}{R^2} \frac{k}{\mu (Sab \frac{p_a}{\rho_a} + \varepsilon)}$$

If $p_g(t) = p_a$, then

$$A = A_0 e^{-\omega p_a t} \tag{18}$$

According to (14), a_0 is related to the initial pressure p_0 and the constant atmospherical pressure p_a by the simple relation

$$A_0 = p_0 - p_a \tag{19}$$

since

$$\frac{dQ}{dt} = \frac{4\pi R^2 \rho_a \frac{k}{\mu} \frac{\partial p}{\partial r}\Big|_{r=R}}{\frac{4}{3}\pi R^3} \tag{4}$$

we obtain

$$Q = \frac{2}{5}(\varepsilon \frac{\rho_a}{p_a} + Sab)(p_0 - p_a)[1 - e^{-\omega p_a t}] \tag{20}$$

We note that as $t\to\infty$, $Q\to\frac{2}{5}Q_m$, whereas the correct limit should be $Q\to Q_m$. This is due to our assumption that the initial pressure distribution is parabolic. However, one would expect greater accuracy when $p_g(t)$, instead of dropping discontinuously from p_0 to p_a, varies continuously and more slowly. Thus in the next section when we consider gas seepage through the coal layer, we shall continue to use Eq. (16).

SEEPAGE OF GAS THROUGH COAL LAYER

It is known that the rate of flow gas in a gas burst is far greater than what one could obtain by computation based on measured diffusion and adsorption coefficients of bulky specimens. The reason appears to be that, when a coal layer is opened up, normal stress is relieved at the exposed surface (Fig. 4), leading to a new state of stress determined by the tectonic pressure p and the gas pressure p_g which varies as a result of diffusion through the coal layer. This new stress state causes the coal to break and produces a considerable amount of fine particles which has been found to be a main characteristic of all gas bursts. Therefore two distinct diffusion processes take place. The first is the escape of gas from the fine particles at a rate much higher than is normally the case on account of the smallness of these particles. The second process is gas diffusion through the coal mass to the free surface. The effective diffusion coefficient k_0 is now greatly enhanced because numerous cracks have formed within the coal layer.

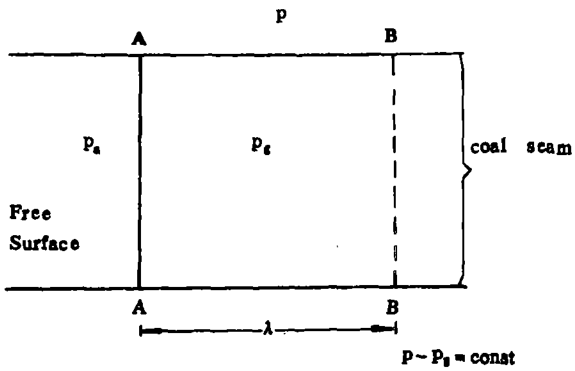


Fig. 4

Consider now the plane one-dimensional case shown in Fig. 4. If we neglect friction at the ceiling and floor of the coal layer, the fractured zone λ can be determined by the criterion $p-p_g=\text{const.}$. As p_g decreases during diffusion, the surface BB bounding the fractured zone will move to the right.

In the following discussion we shall assume, for simplicity, that only a fraction ζ by volume of the coal has been pulverized to fine particles of average radius R. The rest consists of chunks of coal of such large sizes that diffusion of gas out of them can be altogether neglected. We also assume that λ is large so that in studying the gas diffusion process we may take it as infinite. Let k_0 and ε_0 denote the effective diffusion coefficient and porosity of the fractured coal respectively. They are assumed to be constants. Then the isothermal diffusion equation is

$$\frac{\partial}{\partial x}\left(\frac{k_0}{\mu}\frac{\rho_a}{p_a}p_g\frac{\partial p_g}{\partial x}\right)=\varepsilon_0\frac{\rho_a}{p_a}\frac{\partial p_g}{\partial t}+4\pi R^2 n\rho_c\frac{k}{\mu}\frac{\rho_a}{p_a}p_g\frac{\partial p}{\partial r}\bigg|_R \tag{21}$$

where n is the number density per unit mass of the coal and ρ_c its apparent density. It should be pointed out that in writing down (21), adsorption on newly created surfaces of both the fine particles and the more bulky ones has been neglected. We note also

$$\rho_c n\approx\frac{\zeta}{\frac{4}{3}\pi R^3} \tag{22}$$

Eq. (21) and Eq. (7) should be solved simultaneously under the following condition,

$$\begin{array}{lll} I.\ C. & p_g=p=p_0=\text{const.}, & \\ B.\ C. & x=0,\ p_g=p_a & \\ & x\to\infty,\ p_g\to p_0; & \end{array} \tag{23}$$

Interfacial Condition $\qquad p(R;\, x,\, t) = p_g(x,\, t).$

In the following few paragraphs, we shall replace Eq. (7) by Eq. (21) remembering that according to (14),

$$\left.\frac{\partial p}{\partial r}\right|_R = -\frac{2A(t)}{R} \tag{24}$$

This means we adopt all the assumptions involved in deriving (21). After some manipulation we obtain an equation for p_g in the following non-dimensional form,

$$\frac{\partial}{\partial \bar{x}}\left(\bar{p}_g \frac{\partial \bar{p}_g}{\partial \bar{x}}\right) = \frac{\partial \bar{p}_g}{\partial \bar{t}} + \bar{p}_g e^{-\eta\int_0^{\bar{t}}\frac{d\tau}{\bar{p}_g}}\int_0^{\bar{t}}\frac{\partial \bar{p}_g}{\partial \bar{\tau}} e^{\eta\int_0^{\bar{\tau}}\frac{d\tau}{\bar{p}_g}}\, d\bar{\tau} \tag{25}$$

where

$$\bar{p}_g = p_g / p_0,\quad \bar{x} = x / L,\quad \bar{t} = t / t_*, \tag{26}$$

and

$$L^2 = \frac{R^2}{15}\frac{k_0}{k}\frac{1}{\zeta},$$

$$t_* = \varepsilon_0 \frac{\mu L^2}{k_0 p_0},$$

$$\eta = \varepsilon_0 / \zeta\left(Sab\frac{p_a}{\rho_a} + \varepsilon\right).$$

Eq. (25) is to be solved under the following conditions,

$$\begin{aligned} &\bar{t} = 0,\ \bar{p}_g = 1; \\ &\bar{x} = 0,\ \bar{p}_g = \bar{p}_a (= p_a / p_0 < 1), \\ &\bar{x} \to \infty,\ \bar{p}_g \to 1. \end{aligned} \tag{27}$$

We have solved this equation numerically and the results are presented in Fig. 5 in such a form that they can be compared with results obtained below under different assumption.

We start anew by assuming that on account of the smallness of R, the gas pressure within each coal particle is equalized instantly with the surrounding pressure p_g. Then, analogous to (7), we have

$$\frac{\partial}{\partial x}\left(\frac{k_0}{\mu}\frac{\rho_a}{p_a} p_g \frac{\partial p_g}{\partial x}\right) = \left(\varepsilon_0 \frac{\rho_a}{p_a} + S\zeta\frac{df}{dp_g} + \zeta\varepsilon\frac{\rho_a}{p_a}\right)\frac{\partial p_g}{\partial t} \tag{28}$$

where the function $f(p)$ is given in (6). Hence,

$$\frac{\partial}{\partial x}\left(p_g \frac{\partial p_g}{\partial x}\right) = \frac{\mu}{k_0}\left[\varepsilon_0 + \zeta\varepsilon + \frac{\zeta S_a}{\rho_a} b p_a \frac{1}{(1 + b p_g)^2}\right]\frac{\partial p_g}{\partial t} \tag{29}$$

we observe that asymptotic expansion of (25) for large t leads to (29) with the non-linear term $(1 + b p_g)$ replaced by unity. This forms the basis of comparison of numerical solutions of Eq. (25) and Eq. (29).

It is interesting to note that the above equation under the initial and boundary conditions prescribed in (23) admits a similarity solution of the form

$$p_g = p_0 G(\xi), \qquad \xi = ax / t^{1/2} \tag{30}$$

and a is an appropriate constant to make $axt^{-1/2}$ non-dimensional.
Substituting G into (29), we obtain

$$G\frac{d^2G}{d\xi^2} + \left(\frac{dG}{d\xi}\right)^2 + \frac{\mu\xi}{2a^2 k_0 p}\left[\varepsilon_0 + \varepsilon\zeta + \frac{\zeta S_a}{\rho_a}\frac{\beta}{(1 + \frac{\beta}{\bar{p}_a} G)^2}\right]\frac{dG}{d\xi} = 0 \tag{31}$$

where $\beta = b p_a$. When the last term in the bracket predominates as implied by values given in Table 2, the above Equation reduces to

$$G\frac{d^2G}{d\xi^2} + \left(\frac{dG}{d\xi}\right)^2 + \frac{\xi}{2}\frac{\frac{dG}{d\xi}}{(1 + \beta G / \bar{p}_a)} = 0 \tag{32}$$

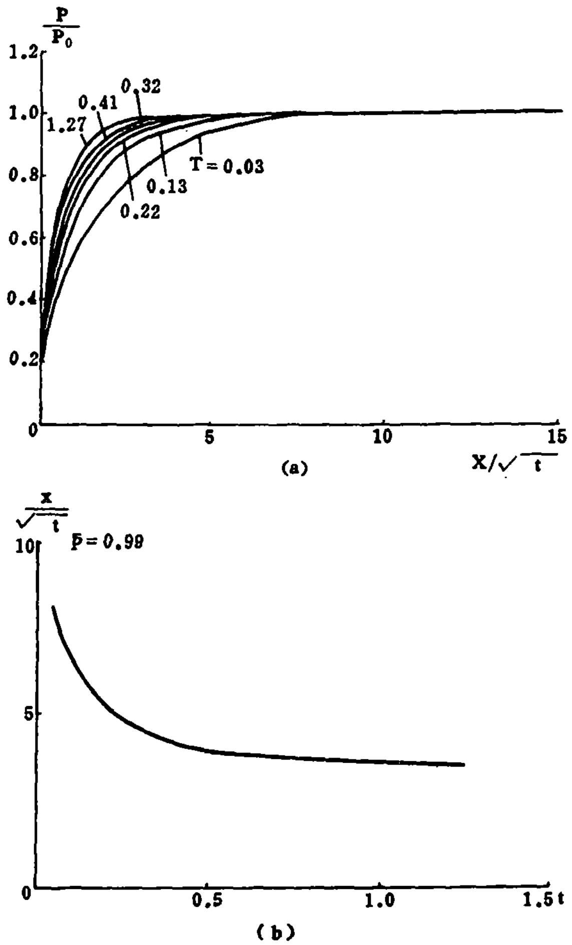


Fig. 5

by setting

$$a^2 = \frac{\mu}{2k_0}\,\frac{\beta}{p_0}\,\frac{\zeta S_a}{\rho_a}. \tag{33}$$

The boundary conditions are

$$G(0) = \overline{p}_a, \quad G(\infty)=1 \tag{34}$$

$G(\xi)$ has been calculated numerically for several values of $\overline{p}_a$ and β. Some of the results are presented in Fig. 6 and 7.

The mass flux q out of the coal layer is then given by

$$\dot{q} = \sqrt{k_0 \beta p_0 \rho_a \zeta S a / \mu}\; t^{-\frac{1}{2}} G'(0) \tag{35}$$

Likewise the pressure gradient at the free surface is equal to

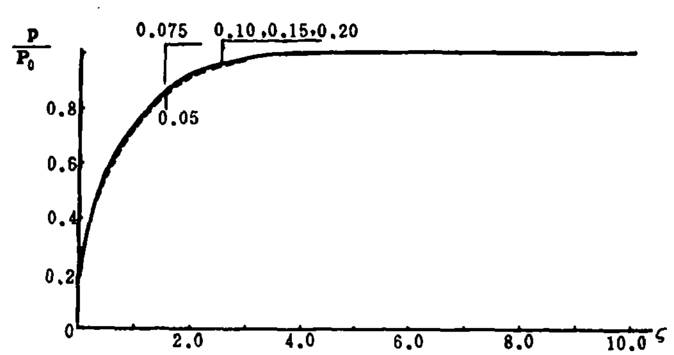


Fig. 6

$$\sqrt{p_0\mu\beta\zeta S_a/k_0\rho_a}\; t^{-\frac{1}{2}}G'(0). \tag{36}$$

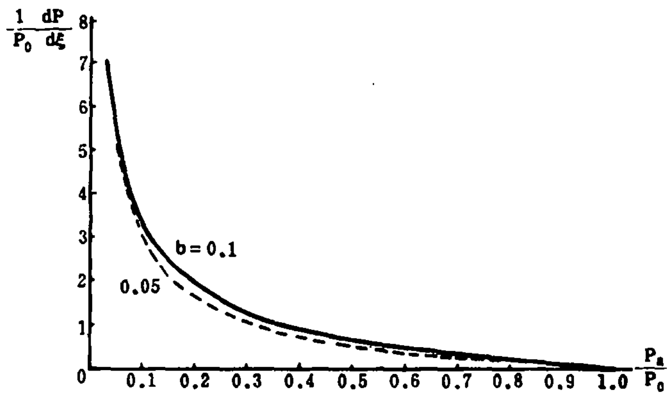


Fig. 7

PRESSURE-VOLUME RELATION AND AVAILABLE ENERGY

The purpose of this section is to calculate the energy ultimately responsible for causing gas bursts. What we are going to calculate represents actually the upper bound, since we neglect energy losses in diffusion out of the fine particles as well as through the coal layer.

As before we assume that a fraction ζ by volume of coal is in the form of particles so fine that the internal pressure resonds instantly to external pressure changes.

Referring to Fig. 8 depicting changes taking place when the volume varies from initial V_0 to $V=\eta V_0(\eta<1)$ and pressure varies accordingly from p_0 to p_g, we have, according to the law of conservation of mass,

$$\varepsilon\rho_0+\zeta\frac{Sabp_0}{1+bp_0}=\zeta\frac{Sabp_g}{1+bp_g}+\varepsilon\rho_g+(n-1)\rho_g.$$

Under isothermal and ideal gas assumptions, the above equation yields the following $p-V$ relation,

$$\frac{V-V_0}{V_0}=\left(\frac{p_0}{p_g}-1\right)\left[\varepsilon_0+\zeta\frac{S_a}{\rho_a}\frac{\beta}{(1+\beta p_0/p_a)(1+\beta p_g/p_a)}\right] \tag{37}$$

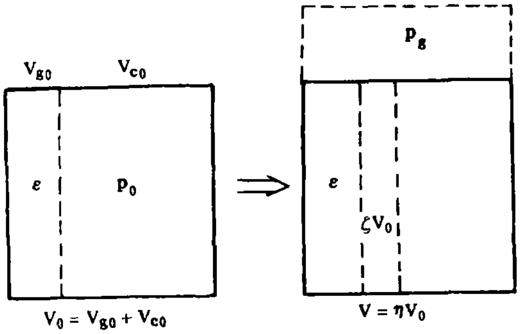


Fig. 8

By integration the available energy e per unit initial volume of coal as pressure drops from p_0 to p_a is then given

$$\frac{e}{p_0}=\left[\varepsilon+\frac{\zeta Sabp_a}{p_a(1+bp_0)}\right]\ln\frac{p_0}{p_a}+\frac{\zeta S_a}{\rho_a}\frac{p_a}{p_0}\left(\frac{1}{1+bp_0}-\frac{1}{1+bp_a}\right)-\frac{\zeta Sap_a}{p_a p_0}\ln\frac{1+bp_0}{1+bp_a}. \tag{38}$$

GAS BURST PREDICTION PARAMETERS AND DISCUSSION

Summing up, the following parameters can be identified as major factors in building up a rational theory of gas burst prediction:

(1) Tectonic pressure, that is $(p-p_0)/\sigma$ be large enough to ensure that a sufficient amount of coal is fragmented and partly crumbled. Here σ may be taken as the crushing strength of coal.

(2) The available energy e must be sufficiently large. This means that non-dimensionally $2e/\rho_c u_*^2$ must be large. Form what we know in rock excavation by explosive, the characteristic velocity should be around 10m/s.

(3) The amount of coal gaining speed up to u_* must be greater than a critical value before the gas pressure is released by diffusion. For the one-dimensional case shown in Fig. 4, both the amount of coal and this critical value can be expressed in terms of length measured from the exposed surface into the coal. With reference to Fig. 9, this condition can be roughly expressed as

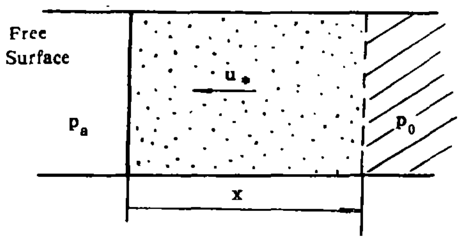


Fig. 9

$$\rho_c x u_* = (p_0 - p_a)t.$$

and x, t are related, according to (30), by

$$\alpha x t^{-1/2} = C(\text{constant})$$

Hence, we require

$$x=\frac{\rho_c u_* C^2}{(p_0-p_a)\alpha^2}>L_* \tag{39}$$

where a^2 is given by (33). The characteristic lenght L_* here may probably be taken to be the size of the large chunks of coal mentioned previously.

(4) The gas release rate should be large. In other words, the characteristic time in (9) must be much smaller than the characteristic time of diffusion through the coal layer, i. e.

$$\frac{R^2 Q_m \mu}{3(p_0 - p_a) k \rho_a} \frac{C^2}{a^2 L^2_*} \ll 1 \tag{40}$$

Qualitatively, the above parameters in (1), (2) and (4) find their expression in engineering terms, some of which are shown in Table 3. In this table $\overline{Q}_m$ is the amount of gas released per unit mass of coal previously pressurized to $3.0 \times 10^6 p$Pa, ΔP and f are the so called initial gas release index and breakage coefficients respectively.

Table 3

$Q_m > 18-20$ m/t
$P > 0.2 \times 10^4$ Pa
$f < 0.35$

The parameter stated in (3) appears to be new.

In conclusion, it should be pointed out that many of the basic quantities such as ζ, k_0, ε_0, R can hardly be determined in the laboratory.

Their value can only be indirectly inferred from field measurements and by examining the debris after a burst. Thus a great deal of laboratory and field studies need be carried out in order one can predict gas bursts with greater confidence and on a firmer scientific ground.

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