THE MECHANISM OF COAL AND GAS OUTBURST EXPLAINED BY DYNAMICS OF SYSTEMS WITH VARIABLE BOUNDARIES

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ABSTRACT

The change of the boundaries of coal seal covering gas (CSCG) are described before the analysis on the basic motions in CSCG. The coupling between the deformation of coal and the migration of gas, and the coupling among the desorption, diffusion, and seepage of gas are discussed respectively. Several assumption about the mechanic properties of CSCG, involving the properties about the desorption, diffusion and permeability, as well as the stress-strain relation of coal post yield, are put forward. The basic variables, constitutive variables and control parameters are analyzed, and the dynamic equations of CSCG in both elastic and plastic zone are constructed respectively. Coal and gas outburst (CGO) is explained from the viewpoint of dynamics of systems with variable boundaries (DSVB). It holds that CGO is a procedure in relation to variable boundaries, which are caused by the failure of material. Whether does CGO take place is decided by the gas migration during the change of boundaries of coal seam; if the fractures are interconnected, and gas is unstuffied, accumulation of gas energy can't exist in the fractured zone of coal-seam, CGO will not happen; on the contrary, if the fractures are closed under the action of crustal stress, and crustose fractured zone may form a kind of structure which can carry load because of the self-sealing of gas pressure; when gas energy accumulated in the fractured zone to a certain extend, the crustose structure will clap, and outburst takes place.

Key words: dynamics of systems with variable boundaries, CSCG, coal and gas outburst, gas migration, failure.

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INTRODUCTION

Dynamics of systems with variable boundaries (DSVB)[1] has come into use in both the analysis on the failure of the overlying strata and the analysis on the harmfulness of water

inrush in coal mines, sufficient attention has not been paid by engineers and scholars at home and abroad. The difficulty in the popularization of DSVB is that the commercial software aiming at the calculation of variable boundary has not been come into the market.
Systems with variable boundaries widely exist in nature, and procedures of variable boundary can often be found in engineering structures. Specially, in mining engineering, almost all the rock structures undergo the change of boundary or interface. The excavation of shaft or drift, the failure of overlying strata or coal seam floor, and the seepage flow of gas or water in rock strata, for example, are typical procedure involving the variable boundaries. In the current article, coal and gas outburst are explained by using DSVB.

A SIMPLE REVIEW ON THE HYPOTHESES ABOUT THE MECHANISM OF GAS AND COAL OUTBURST

Many hypotheses have been presented to explain the mechanism of coal and gas outburst[2-5], such as the gas-dominant-hypothesis, the crustal-stress-dominant-hypothesis, the chemical-reaction-dominant-hypothesis, the uniting-action-hypothesis, as well as the hypothesis of rheology of coal mass. Among these hypotheses, some lays emphasis on the main factor leading to CGO, and the others lays emphasis on the main characters of CGO. Take gas-dominant-hypothesis as an example, it holds that the unstable flow of gas in coal seam is the key factor leading to outburst which is dominated by the pressure, the concentration, and the migration passage of gas. The chemical-reaction-dominant-hypothesis holds that chemical reaction is the main factor leading to outburst. The hypothesis of 'spherical shell losing stability' [6] lays emphasis on the characteristics of the failure surface of the coal seam, it helds that the unstable development of crustose fractured zone is the key factor to lead outburst.

The uniting-action-hypothesis [4] has been broadly accepted because some phenomena in outburst can not be explained by the 'single-factor-hypotheses".

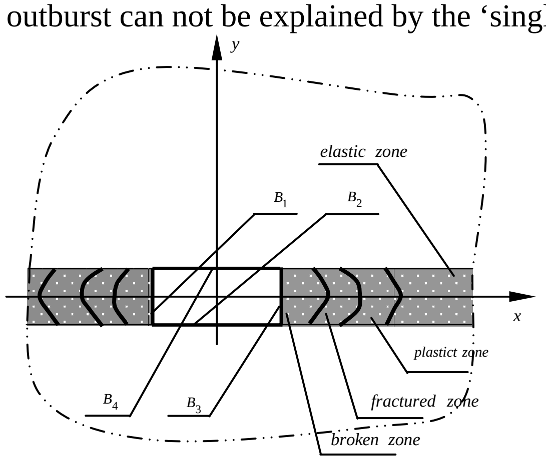

Fig1 Interface among elastic , plastict, fractured and broken district of coal seam

Figure 1.: Interface among elastic, plastic, fractured and broken district of coal seam.

Deyong, Guo; Dexin, Han apply the theory and method of tectonophysics to the prediction of CGO, they think that coal and gas outburst is decided by the tectonophysical environment, including the structure assemblage, the tectonic stress field, and the mechanical properties of tectonic coal, and gas stored in the coal seam. In this hypothesis, the effect of time is not considered. What is described in this hypothesis is a static graph, so the entire process of outburst can not be described by this hypothesis. Then a few of scholars applied rheology to the study on the mechanical behavior of CSCG, and they gave birth to rheology dynamics of coal containing gas (RDCG) [5].

The object of study of RDCG is such materials that their properties is variable, but their distribution in mass is not variable. So the comprehensive description on outburst can not be done by using RDCG. Bing Liang and Mengtao Zhang discuss the mechanical behavior of CGO from a point of view of the coupling between the migration of gas and deformation of coal seam, and presented fluid-solid-coupling-destabilization theory. In this theory, complexity of CSCG and CGO was come into contact with.

However, there are two deficiencies in their dynamic model of CSCG: (a) the plastic deformation of coal seam and its dynamic development are not considered; the change of the interfaces among elastic zone, plastic zone and fractured zone is not considered, and the change of the permeability parameters, diffusion velocity and desorption velocity (or adsorption velocity) are not considered. In fact, the failed zone in coal seam is variable, so the DSVB is necessary to describe the procedure of failure of CSCG.

CHARACTERISTICS OF THE CHANGE OF BOUNDARIES OF CSCG

The material in some zone of CSCG fails under the uniting action of the gravity, gas pressure and outside disturbance, so their bearing capacity is weakened. The worsening of material in bearing capacity results in new damage zones continuously. So, the damage zone of the coal seam is variable. It means that the boundaries of the CSCG, including the interface between every two zones of the elastic zone, the plastic zone, the fractured zone and the overbroken zone. The procedure of the failure of the CSCG possess the characteristics as follows:

(1) the formation and evolvement of fractures in CSCG result in the change of failed zone of CSCG and its boundaries;
(2) local zones near the wall of CSCG fall due to the failure of CSCG;
(3) the connection of fractures covering a large area may cause to coal outburst;
(4) the gases embedding in the coal seam change from an adsorbed state to a free state continuously because of the change of porosity;
(5) if the migration of gas stored in the coal seam is resisted by the crustal stress during the extending of the fractures in the CSCG, a great quantity of gas energy may accumulate in the fractures witch have not connected; When the energy accumulated to a certain amount, the fractures may connect instantly, and powdered coals spurt together with gas, and so CGO takes place.

The change of the failure zone of the CSCG

Because of the affect of the pressure of gas, the gravity force of the CSCG, and disturbance resulted by mining, some zones in the CSCG are destroyed, some fissures come forth and develop into fractures. The occurrence and development of the fissures waken the carrying capacity of the CSCG, and vice verse. So failure zone in the CSCG and its boundaries is variable. One of most notable feature of these variable boundaries lies in that the interfaces between the failure zone and the zone which has not failed are variable, moreover the failure zone include the plastic zone, the fractured zone and the over-broken zone, see figure 1.

The Change of the boundaries near the wall of the CSCG

Because of the separation of material near the wall of the CSCG, the stresses in the new boundaries release, that is to say, the components of σ_x、τ_{xy} and τ_{xz} in B_1 and B_3 become to zero, so do the components of σ_y、τ_{yx} and τ_{yz} in B_2 and B_4, see figure 1. Hence, the material in some zone near these new boundaries may be destroyed. If the fractures connect up one after another, a part of material may separate away from the CSCG, see figure 1. The carrying capacity of the CSCG reduces because of failure of materials. Moreover, the descending in carrying capacity may lead to the further failure of the CSCG, and other materials further separate from the CSCG. So the boundaries of the CSCG are variable owing to the failure of material in the CSCG.

It can be seen that the change of the boundaries of the CSCG is decided by two factors, one is the cut of coal, and the other is the failure of material in the CSCG. And further more, the later is the main factor.

The influence of gas pressure to the change of the boundaries of the CSCG

The gas, which existing in the coal seam, is in the state of adsorption for the great part and in the free state for the small part. When fractures come into being in a local zone, the gas in the adsorption state turns into free state, which leads to the increase of the gas pressure. Because of the failure of the coal, its capacity against penetration weakens, and then the permeability parameters, permeability coefficient, the non-Darcy β factor, and the acceleration coefficient, change remarkably. Meanwhile, the resistance against both the diffusion and the convection of gas decrease. If the fractures connect, the gas will move into the gob by the ways of seepage flow, convection and diffusion, this leads to the decrease of the gas pressure, so the no energy cumulates in CSCG, and CGO cannot occur. If the fractures do not connect, the gas will accumulates in CSCG, and the more the gas in the adsorption state exists, the higher the gas pressure there will be. When the pressure reaches to a certain quantity, the coal will fall, the fractures connect instantaneously, and, under the condition of no dismiss of the pressure, the gas outburst occurs. In a word, if the gas contained in the coal seam is able to moves into gob slowly, the gas outburst cannot occur. The CGO is such a process in which the fractures in a large range of the CSCG connect each other momentarily because the gradual increase of gas pressure and obstruction in the migration of gas. It is obvious that gas plays a vital role in the variable boundaries of the coal. What should be emphasized is that the connect and obstruction of the gas migration route is the fundamental factor in the change of the gas pressure, and the cumulating of the gas energy is significant to the CGO.

The influence of the crustal stress to the change of the boundaries of the CSCG

The stress in the coal seam under the action of the gravity of the overlying rock stratum have an effect on the variable boundaries of the CSCG, this effect can be understood on the basic of following phenomena.

(1) the excavation of coal leads to the bend, fracture, and collapse of the overlying rock stratum, and the load mainly supported by roof transfers to the coal seam, then the stress in the coal seam changes.

(2) the deformation and failure of the overlying rock stratum result in the migration of gas to the fissure of the overlying rock stratum.

(3) the floor heave is blocked by the coal seam, and according to the law of action and reaction, the reaction force of the coal floor on the coal seam changes.

THE BASIC MOTION IN THE CSCG

The coal seam containing gas is a three-phase medium which is consisted of the matrix (solid), the gas in the adsorption state(quasi-liquid), and the gas in the adsorption state(gaseity). Many types of motions just as the deformation of the matrix, the adsorption (desorption), diffusion, and seepage of gas, as well as the couples among all these motions come about.

The desorption of the gas [11-13]

Under a constant pressure, the desorption velocity is

$$V_d = k_2 \theta \qquad (1)$$

Here, k_2 is a constant of the desorption velocity under a certain temperature, θ is the coverage, we have

$$V_d = k_2 \frac{pV_L}{p + p_L} \qquad (2)$$

Here, p is the gas pressure, p_L is the Langmiur's pressure constant; V_L is the Langmiur's volume constant (non dimension). The content of the gas in the coal seam(concentration) is

$$C_1 = \phi \frac{pM}{ZRT} + \frac{pV_L}{p + p_L} \qquad (3)$$

Here, M is the molecular weight of the gas; ϕ is the porosity of the coal; Z is the gas compression factor (non dimension); R is the compression constant of ideal gas. The gas in the adsorption state turns into the free state, and the diffusion and seepage of gas take place. Because the gas pressure, the stress of the ground substance of the coal, and the desorption velocity are variable over the time scale. Until recently, enough attention has not been paid to the relationship between the desorption velocity and the stress (strain) state of the coal seam.

Gas diffusion [11-13]

With respect to the steady diffusion of gas, the diffusion velocity can be described by Fick’s first law, that is expressed by follows

$$J = D_1 \vec{\nabla} C_1 \tag{4}$$

Here, $\vec{\nabla} = \vec{e}_i \frac{\partial}{\partial X_i}$ is the Hamilton’s operator; J is the diffusion velocity per unit area which gas pass through, $\mathrm{kg/s/m^2}$; D_1 is the coefficient of the gas diffusion, $\mathrm{m^2/s}$.

Assuming the diffusion of the coal seam gas in the micro-fissures is resulted by the graduate of the gas concentration, the unsteady diffusion of gas satisfies to the Fick’s second law, we get

$$\vec{\nabla} \cdot (D_1 \vec{\nabla} C_1) = \frac{\partial C_1}{\partial t} \tag{5}$$

Here, D_1 is also determined by the deformation of the matrix of the coal seam and the gas pressure, so D_1 is a variable controlled parameter. Until recently, sufficient attention has not been paid to the relationship between the diffusion velocity and the stress (strain) state of the coal seam.

The seepage flow of gas

Seepage is not a ordinary flow, and we cannot establish the dynamic equations (the Navier-Stokes equation of the Newton fluid, for example) by the kinematical geometric analysis on a micro-unit of fluid, the force analysis, and the constitutive relations. Some experienced relationships can be obtained only by the regression analysis of the experiment data. Until now, the non-Darcy flow is formulated mainly by the Forchheimer relation,

$$\rho c_a \frac{\partial \vec{\mathbf{V}}}{\partial t} = -\vec{\nabla} p - \frac{\mu}{k} \vec{\mathbf{V}} - \beta \rho V \vec{V} \tag{6}$$

Here, ρ is the mass density of the gas; μ is the dynamic viscosity of the gas; β is the non-Darcy β factor, $\vec{V}$ is the seepage flow velocity, $V = \sqrt{\vec{V} \cdot \vec{V}}$.

The deformation of the CSCG[15-16]

The displacement and the stress of the coal seam are formulated by the following set of equations.

(1) The equation of the momentum equilibrium
The stress in the skeleton of a porous medium is generally described by the efficient stress. Adopting the Lagrange description method, the equation of the momentum equilibrium of the matrix of the coal can be obtained directly , that is

$$\rho \frac{\partial^2 \vec{u}}{\partial t^2} = \vec{\nabla} \cdot (\vec{T}' - \phi p \vec{E}) + \vec{b} \qquad (7)$$

Here, $\vec{u}$ is the displacement, X_i ($i = 1,2,3$) is the Lagrange coordinates of the matrix of the coal seam, $\vec{e}_i$ (i = 1,2,3) is the unit vector in the X_i ($i = 1,2,3$) direction, $\vec{E} = \delta_{ij} \vec{e}_i \vec{e}_j$ is the unit second-order tensor, $\vec{b}$ is the force acted on the body.

(2) The equation of the geometry
To expression of the strain tensor by the displacement gradient, the so called equation of the geometry can be written as follows

$$\vec{S} = \frac{1}{2}[(\vec{\nabla}\vec{u}) + (\vec{\nabla}\vec{u})^T] \qquad (8)$$

Here, $\vec{S} = \varepsilon_{ij} \vec{e}_i \vec{e}_j$ and $\vec{u} = u_i \vec{e}_i$ are the strain and the displacement of the groundmass of the coal seam, respectively.

(3) The constitutive equations
For a linear elastic material, the relation between the stress and strain is expressed as follows

$$\vec{T}' = \lambda \Theta \vec{E} + 2G\vec{S} \qquad (9)$$

Here, λ and G are the Lame's coefficient, $\lambda = \frac{E\nu}{(1+\nu)(1-2\nu)}$, $G = \frac{E}{2(1+\nu)}$; E and ν are the elastic modulus and the Poisson's ratio of the coal seam. Equation (9) can be expressed in the component form as follows

$$\sigma'_{ij} = \lambda \Theta \delta_{ij} + G\left(\frac{\partial u_i}{\partial X_j} + \frac{\partial u_j}{\partial X_i}\right), \quad (i, j = 1,2,3)$$

THE DYNAMIC MODEL OF THE CSCG

To study the mechanical behavior of a dynamic system, we usually establish a dynamic model which involves three aspects, the configuration (a set of particles and its geometry position, the mechanical properties of material of which the set of particles is made), variables and parameters, controlling equations, auxiliary equations, definite conditions, and its situation of application. Here, the variable is divided into two classes, one is the basic variables and the other is auxiliary variables (constitutive variable); the auxiliary equations include the constitutive equation and the state equation; the parameters are such physical quantities which express the relation between the based variable and the auxiliary variable (the coefficients, for example); the situation of application is used to judge if the basic equations and the subsidiary equations can be satisfied. The mechanical behavior of CSCG is so complicated that the model should firstly be simplified before the analyses on the behavior and its particularities of CSCG. So hypotheses for the dynamic model of CSCG should be presented. Based on these hypotheses, the equilibrium relations, auxiliary relations, and definite conditions can be obtained.

Some hypotheses

(1) The failure of the coal seam obeys the Coulomb-Mohr's law.

(2) Within the elastic range, the coal obeys the Hooke's law.

(3) Within the plastic range, the coal cannot be harden, that is , it obeys the canonical yield condition of loading and unloding, i.e.,

$$f(\sigma_{ij}) = 0, \quad df = \frac{\partial f}{\partial \sigma_{ij}} d\sigma_{ij} \le 0 \qquad (10)$$

Here, $f(\sigma_{11}, \sigma_{12}, \cdots, \sigma_{33}) = 0$ .Using Coulomb-Mohr's law, we have

$$f = \sigma_1 - K - \sigma_3 \tan^2 \alpha \qquad (11)$$

where $K = \frac{2C\cos\Phi}{1-\sin\Phi}, \alpha = (\frac{\pi}{4} + \frac{\Phi}{2})$, C is the cohesive force, Φ is the internal friction angle.

(4) Strain increment relation can be formulated by the Mises's plasticity potential theory, we assume that the potential function $Q = f$

$$d\varepsilon_{ij}^{'} = d\lambda \frac{\partial Q}{\partial \sigma_{ij}} \qquad (12)$$

Here, $d\lambda$ is the scalar quantity of plasticity, and it express the magnitude of the Strain increment.

(5) The coal porosity is only affected by the gas pressure *p*, and independent on the efficient stress. In fact, the gas pressure is directly related to the efficient stress.

(6) The gas is the barotropic fluid, and its mass density is only related to the pressure itself, satisfying the following state equation

$$\rho = \frac{p}{ZRT}, \quad T = \text{const} \qquad (13)$$

Here, $T = \text{const}$ is assumed to satisfy the condition of the barotropic fluid.

(7) The penetrability parameters of the coal seam can be expressed as functions of the porosity as follows

$$k = k_0 e^{m_k(\phi-\phi_0)} \qquad (14)$$

$$\beta = \beta_0 e^{-m_\beta(\phi-\phi_0)} \qquad (15)$$

$$c_a = c_a^0 e^{-m_c(\phi-\phi_0)} \qquad (16)$$

Here, k_0 β_0, and c_a^0 are the permeability, the non-Darcy β factor, and the coefficient of the acceleration corresponding to the porosity ϕ_0, respectively.

(8) The desorption of the gas is thanked as steady, i.e., in the process of the desorption, the following relation is satisfied.

$$\theta = \frac{p}{p_L + p} \qquad (17)$$

Or expressing the adsorption quantity by

$$x = V_L \theta = V_L \frac{p}{p_L + p} \qquad (18)$$

Here, V_L is the saturated adsorption quantity, which is also named Langmiur's volume constant; p_L is the adsorption constant, which is called Langmiur's pressure constant. x is the real adsorption quantity under the pressure p .

(9) The relation between the gas concentration and the pressure satisfy the expression (3).

(10) The diffusion coefficient of the gas D_1 is also determined by the coal porosity, and we assume that

$$D_1 = D_1^0 e^{m_1(\phi-\phi_0)} \qquad (19)$$

Here, D_1^0 is the diffusion coefficient of the gas corresponding to the porosity ϕ_0 .

Coupling

The coupling between the deformation of the coal seam and the migration of the gas

The effect which the gas pressure exertes on the groundmass of the coal seam is represented by the equation (7), and the effect which the groundmass of the coal seam exerted on the gas is transmitted by the coal porosity. The gas diffusion coefficient, the desorption velocity, the permeability, the non-Darcy β factor, and the coefficient of the acceleration are all expressed as functions of the coal porosity. The porosity and the volume stress of the coal seam can be obtained by the conservation of mass

$$\phi = 1 - \frac{m_0}{m}\frac{1-\phi_0}{1+\Theta} = (1 - \frac{m_0}{m}) + \frac{m_0}{m}(\phi_0 + \Theta) \qquad (21)$$

Here, m_0 and m are the mass density of the coal under the initial moment and moment t, respectively; Θ is the volume strain of the coal seam. When neglecting the change of the mass density, the above expression can be reduced into

$$\phi = \phi_0 + \Theta \qquad (22)$$

It is obvious that the coal deformation (the change of the coal porosity) will result in the change of the properties of the desorption and diffusion of the gas, and the penetrability parameters of the coal seam.

The coupling among desorption, diffusion, the seepage flow of the gas

The coupling of the three types of the gas motions (the desorption, diffusion, and the seepage flow) exists. The desorption of the gas makes the gas from quasi-liquid state, which is adsorpted in the internal wall of the micro-fissure, into free state, and it offers the facilitiy for the diffusion and seepage flow of the gas. For a semi enclosed system, the diffusion and seepage flow of the gas will undoubtedly lead to the decrease of the concentration. For a opened system, since the gas moves into the unit nearby, the quantities of the input and output is certainly related to the (change of) gas concentration. So the concentration have to be considered in the (gas phase) equation of the mass conservation of the CSCG.

In a tine volume of the coal seam, the change of the gas content is caused by both the seepage flow and diffusion, and the equation of the conservation of mass can be expressed as follows

$$\vec{\nabla} \cdot (\vec{J} + \rho \vec{V}) + \frac{\partial C_1}{\partial t} = 0 \qquad (23)$$

Basic variables, auxiliary variables and control parameters

The motion of the CSCG has several modes, and the coupling among these modes is very complex, so the physical quantities which are needed to describe the mechanical behaviors of the CSCG. In order to simplify the dynamic model, the basic variables should be reduced. If the coal seam is in the elastic state all the time, only three basic variables are needed for the solid deformation, whereas, the yield and failure of the coal seam will occur generally. In plastic zone of the CSCG, the Hooke's law is no more true, and the stain increment should be described by the Mises's plasticity potential theory, and nine basic variables are needed (three component of displacement and six of stress). One variable, the gas pressure, is needed to describe the desorption; and one variable, the concentration, is needed to describe the diffusion. According to the expression (4), the gas pressure can be selected as the basic variable. Two variables, the pressure and seepage flow velocity, are needed to describe the seepage flow. Under these circumstances, only two variables, the pressure and the seepage flow velocity, are needed to describe the desorption, the diffusion, and the seepage flow of the gas.

Based what has been motioned above, eleven basic variables are needed to describe the motion of the coal containing gas, that is, the gas pressure *p*, the seepage flow velocity *V*, the displacement of the groundmass of the coal seam $\vec{u}$ (3 components), and the stress $\vec{T}$ (6 components). In the simple case that the groundmass of the CSCG neither yield nor fail, only five basic variables are needed, i.e., the gas pressure *p*, the seepage flow velocity *V*, the displacement of the ground substance of the coal $\vec{u}$ (3 components).

The variables besides the basic variables are all auxiliary variables, including the gas concentration C, the coverage degree θ, the gas mass density ρ, the mass density of the ground substance of the coal m the coal porosity ϕ , the strain (6 components) $\vec{S}$.

The quantities which are used to establish the relations between the basic variables and the auxiliary variables , just as the Langmiur’s pressure constant p_L, the Langmiur’s volume constant V_L, the desorption velocity constant, the compression factor of the gas, the coefficient of the gas diffusion, the elastic modulus of the groundmass of the coal seam, the Poisson’s ratio, the cohesive force C, the internal friction angle Φ .

The dynamic model

A dynamic model consists of a set of basic equations, a set of auxiliary equations and a set of definite conditions. The basic equations which connect the basic variables and auxiliary variables and do not dependent on the material properties are applicable widely. The auxiliary equations which involve the material properties are applicable in a certain range because they are obtained through a series of simplifications.

The dynamic model with no consideration of the coal failure

When neglecting the coal failure, the basic equations of the coal containing gas inculde
(a) the mass conservation equation of the gas, see expression (23).
(b) the momentum conservation equation of the gas, see expression(6)
(c) the mass conservation equation of the groundmass of the coal seam
Combining equation (7), (8) and (9), the mass conservation equation of the groundmass of the coal seam expressed by the displacement can obtained as follows

$$\rho \frac{\partial^2 \vec{u}}{\partial t^2} = (\lambda + G)\vec{\nabla}(\vec{\nabla} \cdot \vec{u}) + G(\vec{\nabla} \cdot \vec{\nabla})\vec{u} - \vec{\nabla}(\phi p) + \vec{b} \qquad (24)$$

And the auxiliary equations in the dynamic model of the CSCG include the following ones:
(a) The relation between the desorption rate of the gas and pressure of gas, see expression (2).

(b) The relation between the concentration of the gas and the pressure of the gas, see expression (3).
(c) The diffusion velocity of the gas and the concentration of the gas, see expression (4).
(d) The state equation of the gas see expression (13).
(e) The relations between the diffusion coefficient of the gas and the porosity of the groundmass of the coal seam, between the permeability parameters of the groundmass of the coal seam and the porosity of the groundmass of the coal seam, see expression (14)~(16) and (19).
(f) The relation between the porosity of the groundmass of the coal seam and the bulk strain of the groundmass of the coal seam, see expression(21).

This model is applicable to elastic zone of the coal seam, and its definite conditions can be given according to the actual conditions.

The dynamic model considering the coal failure

When considering the coal failure, the basic equations of CSCG include:
(a) The mass conservation equation of the gas, see expression (23).
(b) The momentum conservation equation of the gas, see expression (6).
(c) The mass conservation equation of the groundmass of the cola seam, see expression (7) and the auxiliary equations include
(a) The relation between the desorption rate of the gas and pressure of gas, see expression (2).
(b) The relation between the concentration of the gas and the pressure of the gas, see expression (3).
(c) The diffusion velocity of the gas and the concentration of the gas, see expression (4).
(d) The state equation of the gas, see expression (13).
(e) The relations between the diffusion coefficient of the gas and the porosity of the groundmass of the coal seam, between the permeability parameters of the groundmass of the coal seam and the porosity of the groundmass of the coal seam, see expression (14)~(16) and (19).
(f) The relation between the porosity of the groundmass of the coal seam and the bulk strain of the groundmass of the coal seam, see expression (21).
(g) The relation between the strain and displacement, see expression (8)
(h) The constitutive relation in the elastic zone the constitutive relation is expressed by (9) and in the plastic zone it is expressed by (12)
(i) The yield condition, see expression (10).

This model is applicable to such a material as the coal seam where plastic deformation has taken place in some zones, but it is still continuum. The definite conditions can be given according to the actual conditions.

THE MECHANISM OF COAL AND GAS OUTBURST EXPLAINED BY DYNAMICS OF SYSTEMS WITH VARIABLE BOUNDARIES

Whether there will be an outburst in the coal containing gas depends on the evolution of the fissures and the change of the gas pressure. If the gas moves smoothly before the connectedness of the fracture and fissures, the gas pressure will not increase continuously, and then will not accumulate huge energy in the coal, so the outburst will not take place. If there are un-connected fissures in the zone near the coal wall, the migration of the gas will be handicapped and the crustal stress far away from coal wall will increase. So the gas will be pushed to the fissure nearby and it will make the gas pressure around the fissures increasing, leading to the connectedness of the fissures instantaneously. When the gas energy dismisses, quantities of coal fines are cast into the working face and the laneway, and then leads to the coal and gas outburst. When the gas pressure of the fissures increases, the degree of coverage of the gas of the holes near the fissures adds, and with the dismiss of the gas of the fissures, the gas in the adsorption state of the holes near the fissures is translated into the gas in the free state, so the diffusion and seepage flow aggravate.

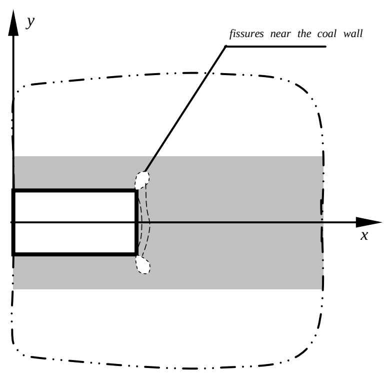

Fig.2 State 1 during the change of coal-seam-boundary

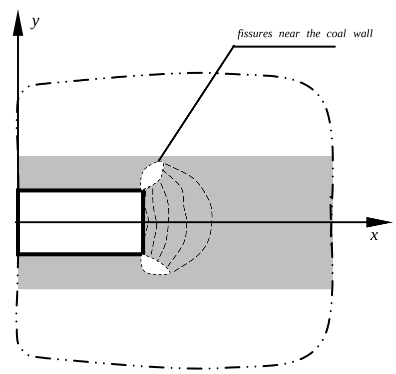

Fig.3 State 2 during the change of coal-seam-boundary

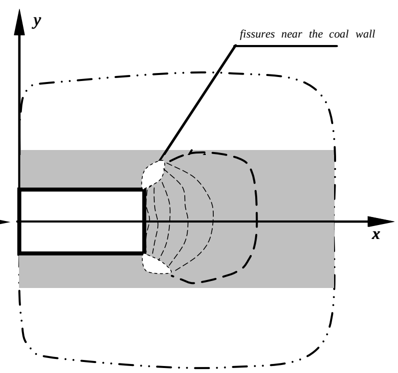

Fig.4 State 3 during the change of coal-seam-boundary

Chenglin, Jiang puts forward a conception "*outburst front*"(that is, the newly and continuously formed exposure surface) when he explained the coal outburst of *cross-cut*. Actually, the "*outburst front*" is just a kind of variable boundaries. The literature [6] classified the outburst process into 6 stages, *i.e.*, the stage of the initial stress, the stage of the concentrated stress, the stage of the failure of the crustal stress, the stage of the coal teared up by the gas, the stage of the coal which is losing stability and casted and the stage of the migration and the static desorption. This literature also represents the thinking of the mechanics with variable boundaries. Tao, Xu, Tianxuan, Hao, Chunan, Tang, and Tianhong, Yang performed the numerical simulation by RFPA2D-Flow, and validated the existence of the outburst front. To combine the study fruits of the literature [6] and [19], the process of the outburst can be explained shortly by the viewpoints of the dynamics of systems with variable boundaries.

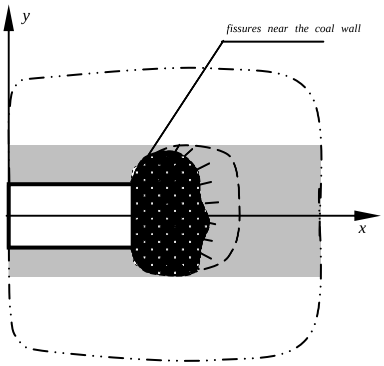

Fig.5 State 4 during the change of coal-seam-boundary

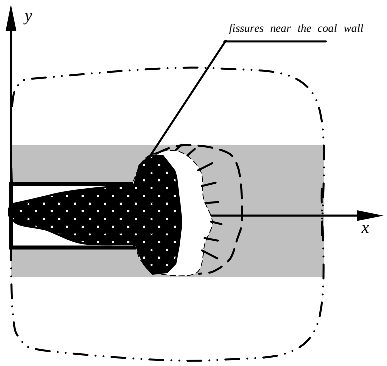

Fig.6 State 5 during the change of coal-seam-boundary

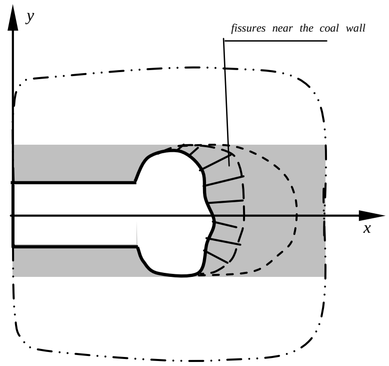

Fig.7 State 6 during the change of coal-seam-boundary

Before mining, the coal is in the static equilibrium state, and mining leads to the sudden dispatch of the material, so the dismiss of the stress on the new-born boundaries equals to adding on the new-born boundaries the surface force which has the same value but the opposite direction to the original stock stress. Since the property of the normal stress is compression, the surface force acted on the new-born boundaries has the tension stress quality. Under the action of the tension stress, the brittle materials can break easily and accompanied by the occurrence of the fissures. These fissures appear firstly near the new-born boundaries which can be called "the fissures of the first generation", and see fig.2. Because the materials near the zones of "the fissures of the first generation" lose the loading capacity, under the gas pressure, "the fissures of the second generation" appears in the coal which is close to the "the fissures of the first generation". In the process of this evolution, "the fissures of the third, fourth, ……, and *n*th generation" come into being one after another, which can be seen in figure 3. Actually, the fissures are born and develop continuously, using the discrete events to describe this process is just for convenience. Then, if the fissures will increase in numbers interminably and abound in the coal? Because of the effect of the crustal stress, the answer is absolutely "no". This effect can be metaphorized as the effect of the cover tyre of the bicycle, that is, whether the inner tube will break is determined together by the gas pressure and the rigidity of the cover tyre. The gas pressure has the function of self packing, *i.e.*, the gas pressure of " the fissures of the ith generation" compresses the coal containing fissures, and then congests the gas migration passage. Meanwhile, since the gas pressure is approximately uniform, the coal in the zone of "the fissures of the first generation" is in the state of triaxial compression and can hardly be ruptured, which can be seen in figure 4. The higher the crustal stress value is, the restrictive effect it exerts on the gas pressure is remarkably. If the crustal stress pressurizes the fissures, restricts the migration of the gas, and even totally prevents the seepage flow and the diffusion of the gas, the gas pressure will augments with time. The gas energy accumulates in the fissures and once breaks through the restraints, it will results in the dynamic damage. If the self packing cannot be achieved, the gas will migrates through holes and fissures into the gob and the pressure will be released. The gas energy cannot accumulate and part of the materials o f the broken zone of the coal break away from the matrix by means of inertial force and gravitation. Indeed, the dust and particles of the fragments in the failure zone may also block the migration passage of the gas, and through a longer steady time, the gas pressure will augments. When the dust and particles are moved with the external disturbance, the obstacles of the gas passage will be removed and the gas pressure will be dismissed instantaneously, but if the coal dose not be moved, the gas outburst will occur. After the outburst, the fissure zones which are not break away from the matrix may become a structure which can have the capacity of bearing loads or collapse. However, where the zones collapse or not, the fissures distribution range, the dimension, and the direction of the arrangement of the coal seam vary with time continuously.

CONCLUSIONS

(1) Because of the mining and the material failure, the coal boundary (including the interface between the broken zone and non-broken zone) varies with time, and the failure of the material is the main factor of the vary of the boundary. Whether there will be an outburst depends on the distribution of the fissure, the connectedness, and the gas migration condition.

(2) Because of the co-action of the gas pressure and the crustal stress, a multistoried shell-like structure can be formed near the coal wall. Under a certain condition, the crustal stress can joint the fissures and the gas pressure can pressurize the shell-like structure, and then the gas of the broken zone can not be moved generally into the gob. When the gas energy cumulates and reaches a certain lever, the shell-like structure loses stability, accompanied by the release of the gas instantaneously, the outburst occurs.

(3) If in the process of the coal seam failure, the fissures connect and the gas moves smoothly, the gas energy cannot accumulate in the failure zone, and then the outburst will not take place.

(4) the dust and particles of the fragments in the failure zone can block the transmission passage of the gas, and through a longer steady time, the gas pressure will augments. Once the dust and particles are moved with the external disturbance, the obstacles of the gas passage will be removed, and the gas pressure will be dismissed instantaneously. Under this circumstances, if the structure does not lose stability, the gas outburst will occur.

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