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AN APPROACH TO THE MODELLING OF SPONTANEOUS COMBUSTION IN THE GOAF

GÖÇÜKTE KENDİLİĞİNDEN YANMANIN MODELLENMESINE BİR YAKLAŞIM

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ABSTRACT

The phenomenon of spontaneous combustion is one of the major hazards encountered in underground coal mines both from the safety aspects and on economic grounds. Every occurence, however small, if not tackled effectively in the early stages can develop into open fire, or explosion of gas or coal dust.

In terms of economy, even dealing with small incidents may be costly in labourship and materials, and in case of a sealing off of a district being necessitated, the loss of face equipment and sterilisation of reserves is potentially great. Therefore, expense and effort in prevention and detection of such heatings, together with a high state of readiness for dealing with a likely event, is completely justified and may be considered as a sound investment. In order to achieve this investment, it may be worth to pinpoint the center of the fire occuring due to autogeneous heating which is supposed to be great assistance to inert it at a least cost and time. Therefore, it is the aim of this article to model the spontaneous combustion in the goaf.

OZET

Kendiliğinden yanma olayı, yeraltı kömür ocaklarında karşılaşılan emniyet ve ekonomi açısından en önemli tehlıİceİerden birisidir. Her ne kadar küçük olursa olsun, zamanında müdahale edilmeyen her olay açık alevli yangın veya kömür/gaz patlamalarına sebebiyet verebilir.

Ekonomik açıdan ele alındığında, küçük yangın olaylarına bile müdahale işçilik ve malzeme açısından pahalı olabilir ve bir panonun barajlanma gerekliliği ise ayak ekipmanının ve büyük miktarlardaki rezerin kaybı ile neticelenebilir. Bu nedenle, bu türlü olayların önceden algılanıp önlenmesi için gerekli olan gayret ve harcalamalar ile daima tetikte bulunulması önemli bir tasarruf kaynağı olarak düşünülebilir. Böyle bir tasarrufu gerçekleştirmek ise, göçükteki kendiliğinden kızışmanın merkezinin tesbitıyle mümkün görünmektedir ki en az maliyet ve zaman harcama ile inertleme işi mümkün kılınabilir. Bu nedenle, bu tebliğde göçükte oluşan kendiliğinden yanmanın modellenmesi hedeflenmiştir.

1. INTRODUCTION

Coal undergoes self oxidation at ambient temperature producing some heat, n the heat in concern is not dissipated, the coal temperature will increase resulting in an acceleration at the rate of oxidation. This oxidation process that will go on until the mass of coal will ignite is commonly known as spontaneous combustion.

Scientist and miners have been and still giving an utmost importance to define the nature of spontaneous combustion as it may cause irreversible problems if not prevented or controlled on time. As the result of spontaneous heating, we may suffer from;

- hazardous gases causing severe fatalities,
- loss of equipment (worthing more than DEM 10.0 million (Singh et al., 1984)),
- loss of an outstanding amount of coal reserves.

Therefore, it is of a high importance to determine the center of a fire in the goaf of a longwall face using a few measurements so that the fire extinguishing process can take place directly in the center of heating with a possible consequence of less time, money and material consumption.

In making a general assumption of that the center of spontaneous combustion is a source of carbon monoxide and heat, there are, therefore, two models that have to be considered. In a first simplified theoretical model, the massflow of carbon monoxide is used for the determination of the center of the fire. This model is called as gas model disregarding the difference in temperature. The second theoretical model considers the mass- and the heatflow and called as heat model.

2. THEORY OF THE GAS MODEL

The massflow in the goaf is purely based on three mechanisms namely convection, diffusion and dispersion. The difference taking place in pressure is the main parameter that forms the convection. The velocity is also influenced by the porosity of the goaf (comparable to the Darcy Velocity (Wactawik et al., 1997) although the density is not constant as in ground water models).

Beside the mass transportation by the convection, the diffusion and the dispersion have to be taken into consideration. These mechanisms are forced by, the difference in the concentration of gases and based on molecular power. By using the Law of Fick, these two transport mechanisms can be described. However, all three transport mechanisms can be given by the utilisation of the Law of Continuity (Gerthsen, 1982; Huette, 1989; Sahimi, 1995):

$$\begin{aligned}
&\qquad\qquad\qquad\qquad\text{(convection)}\\
\frac{\partial(n.\rho)}{\partial t} &= -\frac{\partial(n.\rho.V_x)}{\partial x} - \frac{\partial(n.\rho.V_y)}{\partial y} - \frac{\partial(n.\rho.V_z)}{\partial z} + \\
&\qquad\text{(dispersion and diffusion)}\\
&\frac{\partial}{\partial x}\left[n\left\{(D_{xx}+D_{mol})\frac{\partial\rho}{\partial x} + D_{xy}\frac{\partial\rho}{\partial y} + D_{xz}\frac{\partial\rho}{\partial z}\right\}\right] + \\
&\frac{\partial}{\partial y}\left[n\left\{D_{yx}\frac{\partial\rho}{\partial x} + (D_{yy}+D_{mol})\frac{\partial\rho}{\partial y} + D_{yz}\frac{\partial\rho}{\partial z}\right\}\right] + \\
&\frac{\partial}{\partial z}\left[n\left\{D_{zx}\frac{\partial\rho}{\partial x} + D_{zy}\frac{\partial\rho}{\partial y} + (D_{zz}+D_{mol})\frac{\partial\rho}{\partial z}\right\}\right] + g\ \text{(source and consum.)} \quad ..(1)
\end{aligned}$$

Where;

ρ : density (kg/m^3)
n : part of porosity ( )
$(D_{..} + D_{mol})$: diffusion and dispersion coefficient (m^2/s)
$V_.$: velocity (m/s)
t : time (s)

Additionally, the gas model should also take care of the carbon monoxide production as it is universally accepted sign of spontaneous combustion. The carbon monoxide make has to be measured in the return airway and in the goaf. Therefore, the total volume flowrate of the carbon monoxide source has to be determined in a given period by integration of the total area of the goaf.

The dependence between porosity and pressure difference should also be included in the gas model. Due to this reason, a consideration of the parasitic flow in the goaf can be dropped. The inclination of the goaf causing a difference in levels is determined by the difference in pressure.

Determination of an unknown parameter in a system of equations may only be possible when the number of parameters is equal to the number of solutions in the system. For solving the law of continuity, the change in density has to be known. In the gas model, the density is directly linear depending on the pressure.

A solution is possible with the help of the Law of Movement (Euations 2 and 3 (Gerthsen, 1982)). The dynamic viscosity in these equations of isotherm model could be set constant. The system of equations is soluble utilising the finite element method. As a result, a function of concentration distribution (c = c(x,y,t)) can be obtained. This function merely depends on time and location which means that the highest carbon monoxide concentration can not only often be expected near the centre of the fire, but also behind the goaf due to the transport mechanism. At the point where the gradient of the function is equal to zero, it gives the center of fire location.

$$\rho\left[\frac{\partial V_x}{\partial t}+V_x\frac{\partial V_x}{\partial x}+V_y\frac{\partial V_x}{\partial y}\right]=-\frac{\partial P}{\partial x}+\frac{\partial}{\partial x}\left\{\eta\left[2\frac{\partial V_x}{\partial x}-\frac{2}{3}\left(\frac{\partial V_x}{\partial x}+\frac{\partial V_y}{\partial y}\right)\right]\right\}+\frac{\partial}{\partial y}\left\{\eta\left[\frac{\partial V_x}{\partial y}+\frac{\partial V_y}{\partial y}\right]\right\} \quad \text{....(2)}$$

$$\rho\left[\frac{\partial V_y}{\partial t}+V_x\frac{\partial V_y}{\partial x}+V_y\frac{\partial V_y}{\partial y}\right]=-\frac{\partial P}{\partial y}+\frac{\partial}{\partial x}\left\{\eta\left[\frac{\partial V_y}{\partial x}+\frac{\partial V_x}{\partial y}\right]\right\}+\frac{\partial}{\partial y}\left\{\eta\left[2\frac{\partial V_y}{\partial y}-\frac{2}{3}\left(\frac{\partial V_x}{\partial x}+\frac{\partial V_y}{\partial y}\right)\right]\right\} \quad \text{...(3)}$$

Where;

P : pressure (Pa)
η : dynamic viscosity (kg/ms)

3. THEORY OF THE HEAT MODEL

This model considers the mass and the heat transport. In this case, convection does not only depend on the pressure difference, but also on the temperature difference. Transportation by diffusion and dispersion is influenced by the increase of energy taking place inside the goaf. As the heat model is not isotherm, the way of change in airflow conditions is unknown according to the ideal gas equation. With an approximate knowledge of the physical parameters, the type of change in airflow conditions can only be assumed. As a difference from the gas model, the dynamic viscosity in the equation of movement depends on temperature (r| = T](T)).

In order to take the change in temperature into consideration, additionally the equation of energy has to be used. In this equation, the source of heat (center of fire) and energy consumption (heat transfer between gas and rock) are considered. To find out the capacity of the heat source and the heat transfer, the Fourier and the Biot parameters have to be known. To calculate the capacity, a measurement of temperature in the goaf and near the roudway is necessary. Integration of these three parameters over the square of the goaf by using the Fourier and Newton's Law of cooling leads to the determination of the capacity of the source and the consumption (Equation 4 (Gerthsen, 1982)).

$$\rho.C_p\left[\frac{\partial T}{\partial t}+V_x\frac{\partial T}{\partial x}+V_y\frac{\partial T}{\partial y}\right]=\frac{\partial P}{\partial t}+V_x\frac{\partial P}{\partial x}+V_y\frac{\partial P}{\partial y}+\frac{\partial}{\partial x}\left(\lambda\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(\lambda\frac{\partial T}{\partial y}\right)+$$

$$\eta\left\{2\left[\left(\frac{\partial V_x}{\partial x}\right)^2+\left(\frac{\partial V_y}{\partial y}\right)^2\right]-\frac{2}{3}\left(\frac{\partial V_x}{\partial x}+\frac{\partial V_y}{\partial y}\right)^2+\left(\frac{\partial V_x}{\partial y}+\frac{\partial V_y}{\partial x}\right)^2\right\}+g \text{ (source and consumtion)..(4)}$$

Where;

C_p : specific heat capacity (kJ/kg.K)
T : temperature (K)
X : heat capacity (kW/m.K)

To localise the center of the fire, two possibilities exist. The first solution is made possible by utilising the gradient of function of the carbon monoxide distribution, similar to the gas model.

In the second model, a field of temperature is determined. The center of fire is then found out when the gradient of this function is equal to zero (T = T(x,y,t)).

If the center of fire determined by these two possibilities differs from each other, the gas flow conditions have to be varied until the centers of fire are the same. Therefore, The heat model is an enlargement of the gas model. It considers the change in density as it may vary due to the change in temperature

4. RESULTS

In the formulation of concealed fires in the goaf for mathematical model, many difficulties such as the definition of physicochemical parameters of heterogeneous combustible material together with the filtration properties of the medium may be encountered. The characterising remarks of heat and gas transport related with the process of coal oxidation vary in a wide spectrum in the literature. The mathematical model of heat and gas transport here given is purely based on some assumptions made for simplification reasons.

The application of the combined gas and heat model for the localisation of the center of spontaneous combustion has safety and economical benefits. With this achievement, the fire can be extinguished more quickly and succesfully by injecting e.g. nitrogen directly into the center of spontaneous combustion resulting in the minimisation of material and labour cost and decreasing the risk for firedamp and coal dust explosions.

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