

Full Length Article

Determination and prediction on “three zones” of coal spontaneous combustion in a gob of fully mechanized caving face



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ABSTRACT

The precise division into “three zones” of coal spontaneous combustion in the gob plays a key role for coal fire fighting. This paper presents three-dimensional distribution maps and contour plots for the gases and temperature in the gob by the method of griddata interpolation according to the data (O_2 , CO , CO_2 , CH_4 , and temperature) acquired from in-situ test, and the variation of gases and temperature. It is proposed to comprehensively divide “three zones” by using O_2 concentration of 5–18 vol%, the appearance and disappearance of CO , and the heating rate $K = 0^\circ C/m$. The gas explosion conditions were considered to determine the danger zone of coal spontaneous combustion. The minimum mining speed was calculated to be 4.8 m/day based on the division of the “three zones” in the gob in order to prevent spontaneous combustion phenomenon. Particle swarm optimization (PSO) was employed to optimize the parameters of support vector regression (SVR); the PSO-SVR model was established to predict the temperature of coal spontaneous combustion based on the gases' concentration in the gob and distance from the measuring points to the working face. Prediction results and performance of PSO-SVR model were compared with standard SVR, back propagation neural network (BPNN), and multiple linear regression (MLR). The results indicated that PSO-SVR model had greater prediction accuracy and generalization ability, which can predict the temperature of coal spontaneous combustion in the gob.

1. Introduction

Spontaneous combustion of coal is a natural objective phenomenon in nature that has existed for millions of years [1]. Coal fires have occurred in many countries around the world such as China [2], USA [3,4], India [5], Australia [6], and South Africa [7]. Coal fires threaten valuable resources, the environment, human health, and safety [8]. They have been a worldwide problem, burning plenty of coal resources and producing tremendous greenhouse gases (CO_2 and CH_4) [9–12]. Release of toxic and harmful gases (CO , SO_2 , H_2S , NO_x , etc.) by coal fires not only endangers human health, but also damages the ecological environment, even leading to gas and dust explosions in coal mines [13–15].

Spontaneous combustion of coal is currently one of the main catastrophes to mine safety in production, especially in underground gob of working face [16]. Special mining technology of fully mechanized top coal caving shows the characteristics of high output, and high efficiency, however, which leads to the gob area expanding accordingly,

with a great deal of residual coals left in the gob [17]. At the same time, as mining intensity increases, the quantity of gas emission also increases; unavoidably, ventilation intensity and air pressure in the working face are enhanced substantially, which increases the risk of coal spontaneous combustion in the gob [18]. Distribution of the “three zones (dissipation zone, oxidation zone, and suffocation zone) [1]” in the gob is one of the vital parameters for the prevention and extinguishment of coal spontaneous combustion. Therefore, it is extremely crucial to divide the “three zones” and determine the danger zone accurately. This makes the fire-extinguishing technique in the gob more targeted, so as to avoid the waste of manpower, material, and financial resources. The tube monitoring system is an effective method to predict and catch the trend of coal spontaneous combustion in the gob; Excel is generally used to generate some simple change curves to analyze the observed data. However, the distribution of “three zones” and gases variation in the gob cannot be presented in a three-dimensional expression.

At present, there are mainly three criteria to divide the “three

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Nomenclature

b	bias term
c_1, c_2	acceleration factors
C	error penalty factor
f_i	forecasting value
$iter_{max}$	maximum number of iterations
k	current number of iterations
K	heating rate ($^{\circ}\text{C}/\text{m}$)
$K(\mathbf{x}_i, \mathbf{x}_j)$	kernel function
L	distance from the measuring points to the working face (m)
L_{max}	maximum width of the oxidation zone (m)
L_S	the Lagrangian
n	number of input samples
N	number of particles
P_i	individual extremum
P_g	global extremum
r_1, r_2	random numbers distributed in (0, 1)
R^2	determination coefficient
t_{min}	shortest spontaneous combustion period (day)
v	mining speed of the working face (m/day)
v_{min}	minimum mining speed of possible spontaneous combustion (m/day)
V_i	velocity of the i th particle
$\mathbf{w}$	weight vector
W	width of the working face (m)
X	swarm

X_i	position of the i th particle
$\mathbf{x}$	input vector
$\mathbf{X}$	input matrix
$\mathbf{y}$	output vector
y_i	actual value
$\bar{y}$	mean value of the actual values

Abbreviations

BPNN	back propagation neural network
MAE	mean absolute error
MAPE	mean absolute percentage error
MLR	multiple linear regression
PSO	particle swarm optimization
RBF	radial basis kernel function
RMSE	root-mean-square error
SVM	support vector machine
SVR	support vector regression

Greek symbols

α_i, α_i^*	Lagrange multipliers
ε	precision parameter
η_i, η_i^*	Lagrange multipliers
ξ_i, ξ_i^*	slack variables
σ	width parameter of RBF kernel function
$\phi(\mathbf{x})$	nonlinear mapping function
ω	inertia weight

zones” of coal spontaneous combustion in gob: air leakage velocity, oxygen concentration, and temperature [19]. Air leakage velocity is a vector. Generally, the division of “three zones” can only use a computer to simulate the distribution of air flow and speed under different boundary conditions. However, the boundary conditions of the gob are very complex and difficult to determine, which can lead to a large error between the “three zones” division and the actual situation. Oxygen concentration is the widely used and most effective division method in engineering practice. The distribution of oxygen in a gob is not only related to air leakage, but also to the oxidation degree of residual coals. Theoretically speaking, temperature is the most direct standard to embody the degree of coal spontaneous combustion; however, since

coal is a poor conductor of heat, the process of heat transfer in the gob is still an international challenge. It is a formidable challenge to obtain the temperature of each area in the gob.

Spontaneous combustion of coal is a complex physicochemical process; along with oxidation and the exothermic reaction of coal, corresponding gas products such as O_2 , CO , CO_2 , and CH_4 , are released. Hence, there is a nonlinear relationship between the degree of coal spontaneous combustion and the gas products. The gases easily penetrate the gaps of coal body, so the internal temperature of coal can be judged through analysis of the gases. Researchers have achieved numerous outstanding findings, such as grey system, fuzzy cluster analysis method, and neural networks [20–22]. Support vector machine based

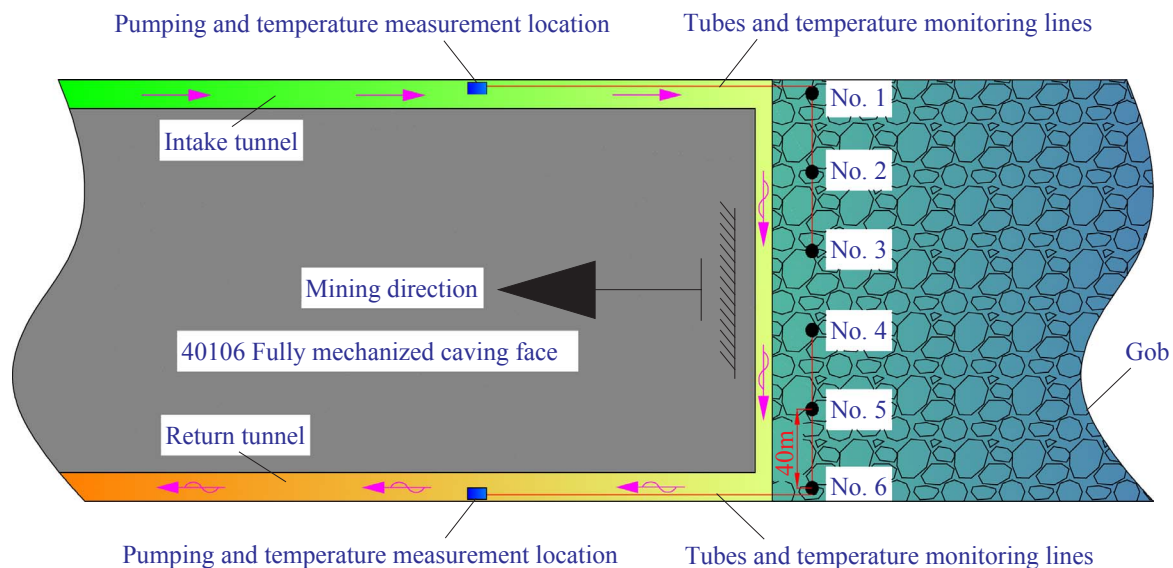


Fig. 1. Location on the monitoring points in gob of 40106 working face.

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