Mining Science and Technology (China) 21 (2011) 581–585

Contents lists available at ScienceDirect

Mining Science and Technology (China)

journal homepage: www.elsevier.com/locate/mstc

A back analysis of the temperature field in the combustion volume space during underground coal gasification

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ARTICLE INFO

Article history:
Received 18 December 2010
Received in revised form 5 January 2011
Accepted 31 January 2011
Available online 22 July 2011

Keywords:
Underground coal gasification
Gasification channel
Temperature field
Combustion space area
Back analysis

ABSTRACT

The exact shape and size of the gasification channel during underground coal gasification (UGC) are of vital importance for the safety and stability of the upper parts of the geological formation. In practice existing geological measurements are insufficient to obtain such information because the coal seam is typically deeply buried and the geological conditions are often complex. This paper introduces a cylindrical model for the gasification channel. The rock and soil masses are assumed to be homogeneous and isotropic and the effect of seepage on the temperature field was neglected. The theory of heat conduction was used to write the equation predicting the temperature field around the gasification channel. The idea of an excess temperature was introduced to solve the equations. Applying this model to UCG in the field for an influence radius, *r*, of 70 m gave the model parameters, $u_{1,2,3...}$, of 2.4, 5.5, 8.7... By adjusting the radius (2, 4, or 6 m) reasonable temperatures of the gasification channel were found for 4 m. The temperature distribution in the vertical direction, and the combustion volume, were also calculated. Comparison to field measurements shows that the results obtained from the proposed model are very close to practice.

1. Introduction

Underground coal gasification (UCG) is one of the research topics of interest to coal miners around the World. It is also an important way to solve a series of technological and environmental problems that exist in traditional coal mining methods [1]. UCG is a promising technology, as it is a combination of mining, exploitation, and gasification, that has been shown to be both technically and economically feasible [2,3]. Highly efficient and green technologies are of concern to both domestic and foreign workers [4]. The size of the combustion space area is important to the process of underground gasification. Cavity growth is a key factor related to continuous and steady production [5]. However, no effective methods have been suggested for measuring the volume of the combustion space. This information is needed to solve some technological problems such as how to prevent ground collapse (e.g., the stability of the space) and the flow of underground water resulting from the collapse [6]. Therefore, the long term development of UCG requires the study of serious problems such as maintaining the volume of the combustion space and evaluation of the stability of the combustion space. An understanding of these points may be obtained through the study of the underground temperature field. Researchers have tried many methods to study the behavior of the cavity during UCG. Some, like Sateesh et al. simulated the process through laboratory experiments [7]. They thought that during UCG the shape and size of the combustion space changed along with the distance between the air inlet and outlet. Therefore, the simulated shape and size of the space was found by adopting seepage CFD software to the laboratory experiments. Britten and Perkins studied the impact of different conditions (e.g., the distance between the air inlet and outlet or the operation time) on cavity growth using a mathematical model to determine the shape and volume of the combustion space [8,9]. In China, Yang established a gasification channel model and a temperature and concentration field model [10]. He thought that the temperature field effect on the heating value of the coal gas was comparatively large. Liu et al. speculated that the occurrence, location, shape, and volume of the combustion space could be observed by transient electromagnetic methods (TEM) [11]. This is the observation of the character of an induced electromagnetic field generated by a geological body over time. Liu et al. speculated that the scope and volume of the space could be monitored by the movement of underground radon gas among rock cracks [12].

Underground coal gasification is a process accompanied by intense combustion, heat-release, and simple and multiphase chemical reactions [12]. Still, despite these scientific studies, it is difficult to accurately predict the shape and volume of the combustion

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1674-5264/$ - see front matter © 2011 Published by Elsevier B.V. on behalf of China University of Mining & Technology.
doi:10.1016/j.mstc.2011.06.018

space because the methods are not well calibrated and the geological situation is quite complex. Therefore, the temperature field model of a cylindrical gasification channel is introduced herein. By studying the combustion space during underground coal gasification the distribution of the temperature field around the channel and the volume of the space are estimated. The changing temperature field around the space is determined for a project case with on-site detection.

2. Temperature field model of the gasification channel

2.1. Establishing the temperature field model

A longitudinal section of the gasification channel is roughly rectangular, ideally. However, in reality this is not so. The effects of heating value and the gaseous temperature field during gasification cause combustion in the side wall of the cavity to be incomplete making the shape round or oval. Suppose a circular channel with a radius r_1 exists and that the average temperature in the gasification channel is T_1. The radius influenced by high temperature is r_2. For $r \geqslant r_2$ the temperature of the rock is near the initial underground temperature.

Suppose the heating value inside the channel is uniform and consider only temperature changes in the radial direction. Solving this problem is made more convenient by the following assumptions:

(1) The impact of seepage on temperature can be neglected because the top and the bottom of the coal seam are both bounded by an impermeable layer. Hence the seepage coefficient is very small [13].
(2) The rock surrounding the gasification channel is homogeneous and the coefficient of thermal conductivity is isotropic.
(3) Because the coal seam is thin the bottom and top of the reaction zone can be considered a floor and a roof [14]. The temperature field around the gasification channel is distributed symmetrically.
(4) The temperature inside the gasification channel is the same as that at the inner wall.

The cross sections along the radial and axial directions are shown in Figs. 1 and 2.

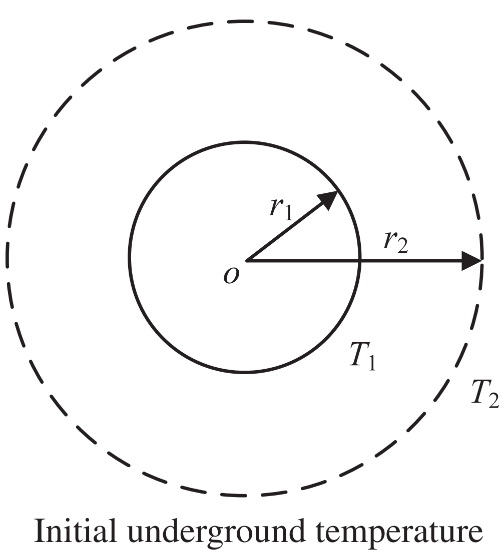

Fig. 1. Radial cross-section of the gasification channel.

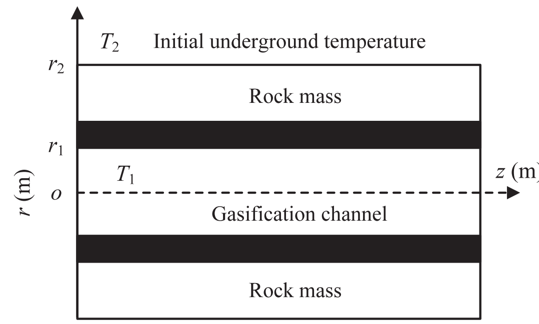

Fig. 2. Longitudinal cross-section of the gasification channel.

The heat conduction equation of a rock–soil mass is given by [15]:

$$\frac{\partial T(r,t)}{\partial t} = \frac{\lambda}{c\rho}\left(\frac{\partial^2 T(r,t)}{\partial r^2} + \frac{1}{r}\frac{\partial T(r,t)}{\partial r}\right) \tag{1}$$

initial condition: $T(r,0) = g_0(r)$boundary conditions: $T(r_1, t) = T_1$, $T(r_2, t) = T_2$

2.2. Solution to the temperature field model

A convenient solution may be found by introducing the excess temperature:

$$\theta(r,t) = T(r,t) - T_c$$

Now Eq. (1) may be written as:

$$\frac{\partial \theta(r,t)}{\partial t} = \frac{\lambda}{c\rho}\left(\frac{\partial^2 \theta(r,t)}{\partial r^2} + \frac{1}{r}\frac{\partial \theta(r,t)}{\partial r}\right) \tag{2}$$

$$\theta(r,0) = g_0(r) - T_c$$
$$\theta(r_1,t) = T(r_1,t) - T_c = T_1 - T_c$$
$$\theta(r_2,t) = T(r_2,t) - T_c = T_c - T_c = 0$$
$$T_2 = T_c$$

To solve these differential equations suppose a solution is:

$$\theta(r,t) = M(r)N(t). \tag{3}$$

Substituting this into the above equations gives:

$$\frac{N'(t)}{(\lambda/c\rho)N(t)} = \frac{M''(r) + \frac{1}{r}M'(r)}{M(r)}$$

Setting both sides of this equation to the constant, $-\beta^2$, gives:

$$N'(t) + (\lambda/c\rho)\beta^2 N(t) = 0 \tag{4}$$

$$M''(r) + \frac{1}{r}M'(r) + \beta^2 M(r) = 0 \tag{5}$$

The general solution of Eq. (4) is:

$$N(t) = C\exp\left(-\frac{\lambda}{c\rho}\beta^2 t\right) \tag{6}$$

where C is constant and B is the zero order Bessel equation with the general solution [16]:

$$M = AJ_0(z) + BY_0(z) \tag{7}$$

A and B are constant in Eq. (7) and

$$J_0(z) = \sum_{m=0}^{\infty} \frac{(-1)^m z^{2m}}{2^{2m} m! \Gamma(m+1)}$$

is a zero order Bessel function of the first kind and