International Journal of Rock Mechanics & Mining Sciences 77 (2015) 300–312

Contents lists available at ScienceDirect

International Journal of Rock Mechanics & Mining Sciences

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

Improvement of coal seam gas drainage by under-panel cross-strata stimulation using highly pressurized gas

Tingkan Lu [a,*], Zhaofeng Wang [b], Hongming Yang [b], Pengju Yuan [a], Yabei Han [b], Xiaoming Sun [b]

[a] School of Energy Science and Engineering, Henan Polytechnic University, Jiaozuo, PR China
[b] School of Safety Science and Engineering, Henan Polytechnic University, Jiaozuo, PR China

ARTICLE INFO

Article history:
Received 24 July 2014
Received in revised form
4 January 2015
Accepted 16 March 2015
Available online 16 May 2015

Keywords:
Gas drainage
Highly pressurized gas stimulation
Fracturing mechanisms
Under panel cross strata drilling

ABSTRACT

Directed at creating fractures and extracting methane in low permeability, high gas-outburst coal seams, this paper presents the results of a comprehensive integration trial of under panel cross strata drilling with a new coal seam stimulation technique: the Cardox system in a colliery located in a major high gas content and outburst prone coal field in the central part of China. On the basis of the coal seam parametric measurements, the precise designation of under panel cross strata borehole patterns and the arrangement of the fracturing and monitoring procedures, the advantages of the Cardox system in creating fractures and improving gas drainage efficiency of low permeability coal seams are: (1) Changing the trend of gas concentration and/or pure gas quantity over time; (2) Maintaining the uptrend of gas concentration and/or pure gas quantity in a relatively long time period, which, in the current case, is ninety days and counting; and (3) Elevating gas drainage to a higher level. Stimulation mechanisms of the highly pressurized gas system have been proposed, and based on these mechanisms, the crushing and fracturing radii created by the highly pressurized gas have been calculated and corroborated well with the field monitoring data.

1. Introduction

The Chinese Governmental Regulation for Preventing Coal and Gas Outburst [1] indicates that the mining and excavation activities are strongly restricted in outburst prone coal seams before completing regional treatment for preventing coal and gas outbursts. Consequently, under-panel cross-strata drilling and drainage has become one of the most frequently used methods for the regional treatment of single outburst prone coal seams in China and other countries [2]. The advantages of this method include being able to eliminate the risk of outburst during the gas control operation and some unwanted effects, such as borehole collapse and coal/gas gush from borehole during and after drilling. Currently, it has become a major technique used for outburst control in soft and outburst prone coal seams in Chinese coal mines.

As the majority of the borehole drilled lies in the rock strata, the major disadvantages of this technique are the high costs and poor drilling efficiency. So, in order to reduce the costs and improve the efficiency of gas drainage for each borehole, as well as effectively prevent the occurrence of coal and gas outbursts during and after drilling, the under panel cross strata drainage technique has been widely used in conjunction with various fracturing techniques [3], such as hydraulic fracturing [4], explosive fracturing [5], water power of scouring [6] and waterjet slotting fracturing [7], etc., in the Chinese coal mining industry.

The method of under panel cross strata drilling and fracturing firstly forms an excavation under the longwall headings along the length of the panel, so called under-panel excavation or under-panel gas drainage excavation, which is dedicated for gas drainage. Then, a number of boreholes are drilled in a fan-shaped pattern from the excavation up to the coal seam, normally with 5 m intervals at the end of each borehole. Then one of the fracturing techniques mentioned above is used in selected boreholes, so as to increase permeability, reduce stress and improve the efficiency of gas drainage in the coal seam around the longwall heading and eventually preventing the occurrence of coal and gas outburst during the stage of longwall heading development (Fig. 1).

There are a number of techniques that may be selected for coal seam fracturing associated with under-panel cross-strata gas drainage. Among those techniques, the explosive fracturing technique is the most effective, as it can be used easily in underground operation, and the efficiency of fracturing is much higher compared with the other techniques mentioned. On the other hand,

* Corresponding author. Tel.: +86 13639624659.
E-mail addresses: tingkan_lu@hotmail.com, tklu@hpu.edu.cn (T. Lu).

http://dx.doi.org/10.1016/j.ijrmms.2015.03.034
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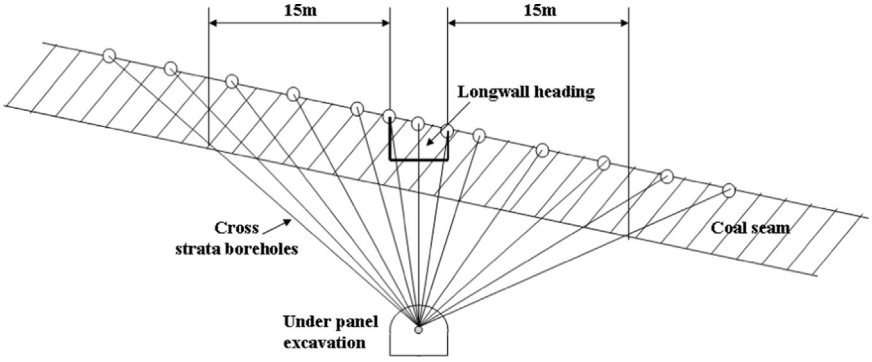

Fig. 1. Under panel cross strata drilling and fracturing.

the explosive fracturing technique has a major disadvantage, that is, if one or more sticks of dynamite did not detonate during the operation, then it will be a serious threat to the safety of heading development and longwall extraction. In order to achieve similar levels of efficiency of coal seam fracturing and eliminate a potential safety risk at the same time, the Cardox system has been introduced as one of the alternative coal seam fracturing techniques.

2. The Cardox system

Although blast-free technologies are not yet considered to be serious competitors to blasting (because of higher cost and lower efficiency), the increase in focus in recent times on the safety of miners might well lead to increased research and development and use of some of these methods [8], such as the Cardox system. The Cardox system is designed to break or aerate materials by discharging carbon dioxide at high pressure into the material. In order to operate the system in any material, a range of tubes (containers) are available. In turn, these provide a range of discharge pressures. The combination of various tubes, discharge pressures and chemical energizers (heaters) allow over twenty different discharge characteristics, which gives flexibility to different end users and typical applications [9].

As it was originally developed for use in coal seams, the Cardox system utilizes a release of inert carbon dioxide gas, the same gas used in fire extinguishers, making it suitable for use with hazardous, flammable or combustible materials [10] and environments. The rapid release of carbon dioxide gas produces a powerful heaving force that pushes on the solid material, effectively breaking it up into smaller particle sizes or creating fractures in the solid material, for instance, the coal seam. This has led to claims that it can reduce noise, vibration, dust and flyrock, as well as other advantages. These advantages trend towards necessitate the development and exploration of the potential of new and improved concepts of coal seam fracturing. One of the promising concepts that warrants in depth evaluation as a tool for rock/coal fragmentation is the non-explosive rock-breaking technology—the Cardox system, based upon penetrating core fracture concept [11].

2.1. Composition of the Cardox system used in the underground of the coal mine

The composition of the Cardox system used in the underground of coal mines in China is different from its current traditional application, e.g. cement industry, and it contains three subsystems: the fracturing system, the filling rig and the handling system. The fracturing system is used to provide the function of creating fractures on the target objective—the coal seam. It consists of a few components, including the carbon dioxide container (also called a tube), which is used to store liquid carbon dioxide; the tube head, used to connect electric wire; the discharge head, which is used to release the high energy gas; the heater which is used to raise the temperature of the liquid carbon dioxide stored in the container; and the shear disc, providing a function equivalent to a safety valve, that is, when the pressure in the container is larger than a designated value, a shear failure of disc will occur, and the high pressure gas will be released from discharge head. The filling rig is used to fill the container with liquid carbon dioxide. It contains a pump and a specially designed frame to hold the carbon dioxide container during the filling. Finally, there is the handling system. Unlike other applications, the target coal seam is normally not very close to the operation site; therefore, it is necessary to deliver the fracturing system to the location required through the borehole drilled. On the other hand, the chemical heater used in the fracturing system is to be detonated electrically, so an electric circuit must be formed in a relatively long range before the Cardox system can be operated.

Therefore, the handling system has two basic functions in coal mine application that is, the delivery function and electrical conduction function. In order to satisfy these two requirements, the drilling pipe equipped with electric wire is designed associated with different types of drilling rig. Under such a system, the fracturing system can be delivered into any location within the coal seam regardless of the borehole depth.

2.2. Mechanisms and safety characteristics of the Cardox system

The liquid carbon dioxide is stored in a sealed and reusable container and generates an additional volume of gas when it is vaporized by an electronically ignited chemical. With the instantaneous increase in pressure within the container, the shear disc ruptures and allows the highly pressurized carbon dioxide gases to discharge into the surrounding coal seam. In this process, the volume of the liquid carbon dioxide will expand up to 600 times within 20 ms. Ultra high gas pressures, varying from 160 to 270 MPa, may be generated. The energy provided by the Cardox system can be determined as [12]:

$$E=\frac{1}{2}V^2+\left(\frac{n}{n-1}\right)\left(\frac{P}{g_o}\right)\left(\frac{P_o}{P}\right)^{0.5} \quad (1)$$

where E is the energy provided [J], V is the velocity of releasing gas from nozzle [m/s], P is the pressure in outside of the Cardox tube [MPa], P_o is the pressure in the Cardox tube [MPa], g_o is the gas density in Cardox tube [g/l], and $n=1.4$.

Where the safety of Cardox system is concerned, the experimental work on the safety of the chemical heater bas been conducted by the Health and Safety Executive Research and Laboratory Services Division, UK [13], the results indicated that