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Research into comprehensive gas extraction technology of single coal seams with low permeability in the Jiaozuo coal mining area

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ABSTRACT

For a low permeability single coal seam prone to gas outbursts, pre-drainage of gas is difficult and inefficient, seriously restricting the safety and efficiency of production. Radical measures of increasing gas extraction efficiency are pressure relief and infrared antireflection. We have analyzed the effect of mining conditions and the regularity of mine pressure distribution in front of the working face of a major coal mine of the Jiaozuo Industrial (Group) Co. as our test area, studied the width of the depressurization zone in slice mining and analyzed gas efficiency and fast drainage in the advanced stress relaxation zone. On that basis, we further investigated and practiced the exploitation technology of shallow drilling, fan drilling and grid shape drilling at the working face. Practice and our results show that the stress relaxation zone is the ideal region for quick and efficient extraction of gas. By means of an integrated extraction technology, the amount of gas emitted into the zone was greatly reduced, while the risk of dangerous outbursts of coal and gas was lowered markedly. This exploration provides a new way to control for gas in working faces of coal mines with low permeability and risk of gas outbursts of single coal seams in the Jiaozuo mining area.

1. Introduction

Antireflection pressure relief is an effective method to improve gas extraction rates [1–3]. Based on mining pressure relief theory, protecting the exploitation of coal seams has become an effective way of controlling gas in multi-seam mining in China. Protecting the exploitation of seams not only reacts to antireflection pressure relief of coal outbursts, but can also effectively release gas and ground stress and hence has become an effective method of prevention of coal and gas outbursts [4–6]. Lacking adequate conditions for protecting the exploitation of a single seam with low permeability and a high risk of gas outbursts, pre-mining drainage of coal seams that have been worked is the only method to control regional gas controlling. However, high gas outburst seams, with low permeability and poor drilling conditions, require long pre-drainage times and the existence of blank tapes at working faces. Not only does this threaten the conditions for safe production, but also seriously restrict the safety and productivity of coal mines. Theoretical research and practice have shown that coal is in a state of pressure relief affected by mining activity within a specified range of the stope, whose flow-increasing effect appears as antireflection [7–9]. According to flow theory the occurrence of coal seam gas, given the conditions of similar basic gas-geology, antireflection pressure relief is the most important factor controlling the amount of gas draining from drill holes [10,11]. Based on this theory, we have used the example of the Jiaozuo mining area as a typically developed single low permeability and high risk gas and coal bed outburst area to study the technical foundation of gas extraction, the distribution of pressure release zones and the increasing effect of permeation at its working face, affected by mining activity. Given the theoretical basis for gas extraction in pressure release zones, we carried out studies and applications of integrated gas extraction technology in single coal seams with low permeability. Practice has shown that pressure release zones are ideal regions for highly efficient gas exploitation, with marked effects of its utility model that suppresses the risks of emission and coal and gas outbursts.

2. Strata behavior regularity of excavation working face and width observation of stress relaxation zone

Because of the effect of coal mining activity, support conditions change. In a sequence from the bottom of the mined zone, followed

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by the formation of the caving-, the fracture- and bending-subsidence zones above the gob area, roof strata movements change [12]. Roof strata stress of different coal seams in front of the working face may change along the seams to the front followed by the formation of a pressure relief zone, a stress concentration zone and an original stress zone (see Fig. 1) [13]. Because of top coal caving from a false leaf trace roof, the immediate roof caves as mining progresses and in the end the cantilevered roof will collapse, resulting in a wide range of overlying strata relief. Given the decrease of the support pressure of the coal in the pressure relief range, a stress relaxation zone will be formed in first instance. With the release of the coal stress, where original fractures open or expand. New fractures will be generated and regional permeability of coal increases rapidly. Part of the adsorbed gas is analyzed and together with the free gas this adsorbed gas migrates rapidly to the free space, showing a ‘‘flow effect by relief’’, which is the ideal area to improve the effect of pumping gas. Within a specified range below the stress relaxation zone, due to the cyclical destruction and instability of the rock wall, coal pressure is transferred downward to form a stress concentration zone, where stress will increase, fractures and large pores will close, decreasing the permeability of the coal seam and hence, the conditions for desorption and seepage of coal gas. Below this level, coal and its rock mass have not yet been affected by mining activity. This zone bears normal stress, called the original stress zone, where the gas flow is not affected by mining.

Theoretical studies suggest that the width of the stress relaxation zone is proportional to the thickness of the coal seam, while the side pressure coefficient and the depth of coal mining are inversely proportional to the friction coefficient of the interface and the tensile strength of coal [14]. Because differences among some factors in the same mine are not large, we can analyze the variation in underground pressure and amount of gas flow from the boreholes at the working face to investigate the width of the stress relaxation zone [15,16]. The Jiaozuo coalfield is a typical low permeability and high gas outburst single coal seam zone in China. The main seam is the #21 coal seam of Shanxi formation, with an average thickness of approximately 6 m, a high coal gas content (generally 20–34 m^3/t daf), and high pressure (0.7–2.42 MPa). The measured seam permeability coefficient ranges between 0.11 and 5.86 $m^2/(MPa^2\ d)$. Pre-pumping the coal gas is the most important technology to remove the risk of an outburst at the working face. Currently, the major mining methods at Jiaozuo are top-coal mining and slice mining, with mine technologies such as inclined longwall mining and fully-mechanized mining. During our tests, we selected from the Jiaozuo Industrial (Group) Co., LTD., the working faces of the #14101 Jiulishan seam and of the #22041 Yanmazhuang seam. Given the variation in mine pressure distribution in different stress zones and gas flow patterns, we investigated the width of the advanced stress relaxation zone at both of working faces with the help of two conditions, i.e., the underground pressure at the working face and the amount of gas flowing from boreholes.

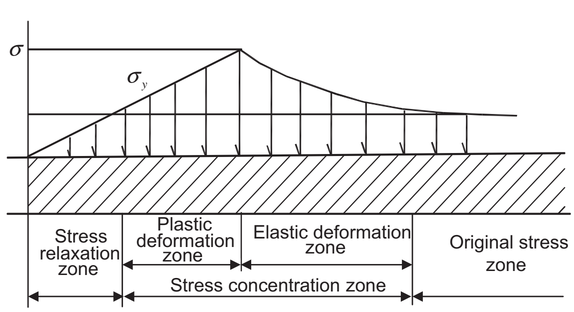

Fig. 1. Schematic diagram of the front of a coal bed showing support pressure distribution at the working face.

From our investigation of mine pressure distribution regularity and the variation of gas flows in the various stress zones (Figs. 2 and 3), we see that the advanced work concentrates stress in front of the working face and exceeds the constant. Beyond 20 m, the coal seams gradually become areas of stress concentration, where roof pressure increases, coal fractures close, permeability reduces, gas flows from drilling decreases to an average gas flow of only 0.03 m^3/min. Within 10–20 m from the face, the coal forces the stress concentration zone into the transition zone and further into the stress relaxation zone, where permeability and gas flow from drilling gradually increase to 0.12 m^3/min. Less than 10 m from the face and as the distance to the working face decreases, the effective extraction length of drilling is reduced, resulting in a declining gas flow. Because the roof lets go and collapses in this area, the pressure in the coal seam is fully released and the fractures in the coal seam increase substantially. The volume extracted by drilling is still increasing. Given our data on mining pressure at the working face and our investigation of gas flows, we consider the range of the full stress relaxation zone in front of a slice of the mining working face to be 20–30 m, where a distance of 20 m or less is clearly within the range of a stress relaxation zone under normal conditions.

3. Analysis of basic technology of gas extraction in preact stress relaxation zone

Methane drainage is not only related to drainage time, negative drainage pressure, the diameter of the drill hole, drilling depth but also to other parameters depends on the permeability of coal seams [17]. When underground coal is not affected within an influence radius of drilling during the initial stage of drainage, coal fractures are connected, adsorbed gas is gradually desorbed and the extraction results are quite good. When the drainage time is extended, the gas flow from drilling attenuates quickly. As mining activities are carried out, the stress balance in the coal is broken; stress redistribution takes place in front of the working face to reach a new balance. As the working face advances, the front of the coal is unloaded within a specific pressure range and coal fractures become further connected, forming a stress relaxation zone. Meanwhile, within a specified range of deep coal, a higher stress appears, holes and fractures close, forming a stress concentration zone in the area of mining activities. In this area, not only is construction difficult, but poor permeability is also a problem, given the original stress area in this deep area. In stress relaxation zones, the permeability of coal seams increase, the conversion rate of the adsorbed gas to free gas increases, a new rise in the amount of drill gas inevitably occurs, thus making the area an ideal region for drawing gas fast and efficiently. According to a study by Zhou and Lin, an application of this technology to draw gas into the stress relaxation zone, shrinkage of coal will certainly occur, giving rise to two benefits [10]. On the one hand, coal strength will be increased; on the other hand the permeability of coal seams is further improved, thus reducing the methane pressure gradient and effectively preventing coal and gas outbursts. As the coal working face advances continuously, there will be always stress relaxed coal in certain areas of the working face. The determination of the head relief pressure area of a coal mining face is the basis for a suitable arrangement of gas drill holes and for strengthening methane drainage measures and management in a stress relaxation zone. Therefore, reducing the risk of gas emissions for the purpose of safe mining can be achieved by strengthening the management of pre-drainage holes, arranging drainage holes suitably, optimizing drainage parameters. Such achievements should