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Phenomenon of methane driven caused by hydraulic fracturing in methane-bearing coal seams

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ABSTRACT

The methane concentration of the return current will always be enhanced to a certain degree when hydraulic fracturing with bedding drilling is implemented to a gassy coal seam in an underground coal mine. The methane in coal seam is driven out by hydraulic fracturing. Thus, the phenomenon is named as methane driven effect of hydraulic fracturing. After deep-hole hydraulic fracturing at the tunneling face of the gassy coal seam, the coal methane content exhibits a "low-high-low" distribution along excavation direction in the following advancing process, verifying the existence of methane driven caused by hydraulic fracturing in methane-bearing coal seam. Hydraulic fracturing causes the change of pore-water and methane pressure in surrounding coal. The uneven distribution of the pore pressure forms a pore pressure gradient. The free methane migrates from the position of high pore (methane) pressure to the position of low pore (methane) pressure. The methane pressure gradient is the fundamental driving force for methane-driven coal seam hydraulic fracturing. The uneven hydraulic crack propagation and the effect of time (as some processes need time to complete and are not completed instantaneously) will result in uneven methane driven. Therefore, an even hydraulic fracturing technique should be used to avoid the negative effects of methane driven; on the other hand, by taking fully advantage of methane driven, two technologies are presented.
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1. Introduction

Through main hydraulic crack extension, airfoil branch crack propagation, and the coal absorbent moist function, coal seam hydraulic fracturing can meet certain project needs, such as structural transformation, strength weakening, and coal permeability improvement [1]. Coal seam hydraulic fracturing is an effective technological measure for improving seam permeability to drain methane, preventing coal and methane from outburst, and treating rock burst, and has been widely applied in coal mines. Traditional coal seam injection, which is characterized by permeation and water absorption to moisten and soften the coal seam, has been applied for decades in coal mines; and it is significantly different from coal seam hydraulic fracturing. According to the formation process of coal, the higher the degree of coal metamorphism is, the more the pore in coal is and the higher the generated methane content is; after late tectonic movements, many joint and fissure are formed in the coal seam, so the coal seam becomes a typical dual-porosity medium. Part of the generated methane in the coal metamorphosis spreads to the outside world, however, due to the good airtight performance of roof and floor rock mass of coal seam, there is still a considerable amount of methane retained in the coal. Moreover, the methane content of the coal seam increases with the buried depth. Most of coal seams are methane-bearing coal seam and methane occurs in coal seams in a free or absorbed state [2–5].

The author discovered that the methane concentration significantly increased in gateroad air flow when the hydraulic fracturing was conducted in high gassy coal seam, the methane in coal seam was driven out by the hydraulic fracturing. Therefore, this phenomenon is called methane driven phenomenon (or effect) of hydraulic fracturing. Later investigation discovered that the methane concentration of the return current also often increases during the gassy coal seam water injection process. This must be the result of methane driven effect. Since the phenomenon of methane driven caused by water injection has not led to any obvious disasters for many years, it has attracted very little attention in the coal industry. With the gradual reduction of shallow coal resources, plenty of coal mines gradually become subject to deep mining. The deep coal seam methane content is high, and methane

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driven effect in this kind of seam hydraulic fracturing (water injection) process may lead to methane overrun in air return and an increase in local methane content and pressure, and make an adverse effect on the control of coal and gas outburst and gas explosion. Therefore, this phenomenon must be comprehensively understood and its basic laws must be mastered. In allusion to methane driven, we should enhance its advantage and avoid disadvantage in practice.

2. Rising phenomenon of methane concentration in return air caused by hydraulic fracturing in a gassy coal seam

In the Gedian Mine, belonging to the Shenhuo Group, its 3# coal seam is a high-quality anthracite and its coal seam joints develop well with crushed coal mass. The coal Protodyakonov coefficient f is about 0.48. The coal seam thickness is 0.68–2.8 m, with an average of 1.71 m; and its inclination is 3–10°, with an average of 5°. The coal seam lays stable with a simple structure. Its relative methane content is about 13.32 m^3/t. The maximum methane pressure is 1.04 MPa. The seam permeability coefficient is 1.36 $m^2/(MPa^2\ d)$, and the initial methane irradiation velocity is 13.54 mmHg. This coal seam belongs to the coal and methane outburst coal seam.

The roadway of the 33,022 working face is excavated along the seam roof. The roadway section is a right trapezoid with two vertical roadway walls. Its width is 4.4 m and the intermediate height is 2.8 m. A detailed explanation of coal seam hydraulic fracturing conducted in August 2011 is as follows: hydraulic fracturing holes are drilled perpendicular to the coal wall and along the seam at intervals of 6 m; their depth is 60–70 m and the hole diameters are 89 mm; with PD material (a kind of new slurry material for drill sealing) sealing, the sealing depth of the hole is 15 m. A specialized injection pump is adopted. With an underground hydraulic fracturing monitor, the orifice water pressure can be monitored and graphically displayed in real time. During the hydraulic fracturing process, the methane concentration of the return current and its changes are monitored by a methane monitor hanging on the roof, near hole 23# (Fig. 1). No operations that lead to significant increases in methane emission, such as drilling or blasting, are carried out in this roadway at that time.

The relationships among injection water pressure, the concentration of methane and time for hole 25# are shown in Fig. 2. Joints, cracks, and pores of the coal seam are well developed with high filtration after pump injection for 13 min, with the water pressure of hydraulic fracturing attaining a maximum value of 7.4 MPa, namely, the breakdown water pressure was 7.4 MPa and the drilling hole ruptured into hydraulic cracks. Then the water pressure gradually decreased. After injecting water for 28 min, the expansion of a wide range of hydraulic cracks led to a further increase in filtration per unit time, the water pressure dropped to an average of 1.5 MPa, and water seepage began to occur on the

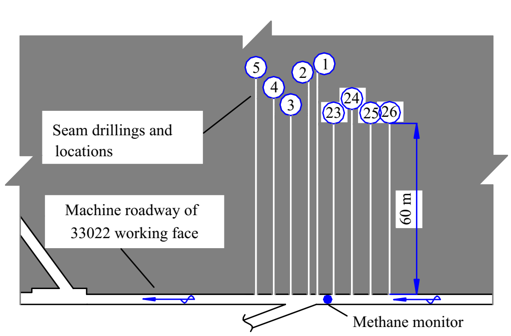

Fig. 1. Top view for locations of the drilling holes and the methane monitor.

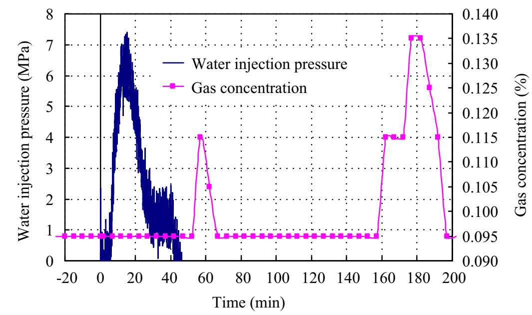

Fig. 2. Plots of the injection pressure and the roadway methane concentration vs. time.

gateroads wall, and the dreg phenomenon appeared on the coal wall near hole 25#. Water pressure, between 28 and 40 min, remained unchanged on the whole, indicating that the hydraulic cracks basically extended to the surface of the coal roadway wall; near hole 23#, there was water running obviously from the bolt hole (about 0.5 m to hole 23# from the tunneling face direction) and the checking hole (about 1.3 m to hole 23# from the tunneling face direction). During the injection process, a "crackling" sound could be heard many times from the coal wall, indicating that the fracturing effect was very significant. About 40 min later, water pumping was stopped when a greater "crack" sound could be heard from the surrounding coal roadway wall. Then the orifice water pressure quickly decreased. About 42 min later, the orifice water pressure was essentially 0 MPa.

After disconnecting the injection pipeline and discharging the water from the drilling hole, a portable methane detector (with a measurement limit of 4.5%) is used to monitor the orifice methane concentration. The detector alarm siren will immediately go off, indicating that the methane concentration has exceeded the measurement limit. We put our palm near the drilling orifice, and methane spraying out from the hydraulic hole could clearly be felt. Within 15 min after the injection, the methane concentration of the return current, near hole 23#, rose to 0.115% from the previous 0.095%. The methane concentration within the roadway increased by 0.02%, indicating that the coal seam hydraulic fracturing (water injection) had a driving effect on the methane within the coal seam. Within 115 min after the injection, the methane concentration within the roadway began to rise and the maximum increase of methane concentration was 0.040%, and lasted for 40 min. It illustrates that the methane driven phenomenon is obvious, and the process of methane migration and desorption has time effect.

The pore-water pressure distribution from the drilling hole outward along the radial direction is gradually decreasing trend in the coal seam during the course of hydraulic fracturing. Because of the sudden drop in drilling water pressure after hydraulic fracturing, the pore-water pressure distribution near the drilling hole rapidly turned into a relative increase, forming a large pore-water pressure gradient. The pore-water pressure gradient, then, resulted in a large amount of high-concentration methane spraying out from the drilling hole. Under the effect of methane pressure gradient, the coal seam methane migrated and diffused into the gateroads gradually.

3. Verification of methane driven phenomenon

3.1. Test conditions

The 2-2# coal seam of the Xuehu Mine, Shenhuo Group, is buried about 800 m deep with developed fissures. The coal seam thickness is 1.0–3.1 m (mostly between 2 and 3 m although some

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