JOURNAL OF PURE AND APPLIED MICROBIOLOGY, March 2013. Vol. **7**(1), p. 335-340

Experimental Research on Microbial Increasing Permeability of Coal Reservoir and its Significance

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(Received: 11 February 2013; accepted: 05 March 2013)

The permeability of coal reservoir is the critical parameter of CBM (coalbed methane) development and mine gas control, but at present only the physical measures on increasing permeability are widely used in coal reservoir. According to the formation mechanism of biogenic methane, the author put forward an idea of microbial increasing permeability for coal reservoir. Through microbial enrichment in mine water, microscope observation, isothermal adsorption and permeability test, the results show the width and number of fracture increased significantly after microbial treatment, which indicates the effect of the microbial increasing permeability of coal reservoir. Meanwhile, the higher the original permeability of coal reservoir is, the more obvious the effect is, and low rank coal is more advantageous in that way. This paper provides an experimental support for biological technology in CBM development and the application of mine gas disaster control.

Keywords: Microbe, Microbial enrichment, Coal reservoir, Permeability, Coal rank, Coalbed methane.

Nowadays, people have gradually reached a general consensus at using coal as the material to produce methane by microbe in middle-low rank coal reservoir. As long as the temperature, pressure, pH, Eh, mineralization and nutrients are meeting the demands of microbe's growth (Speece, *et al.,* 1987), it is completely possible to transform the coal into methane (Blaut, 1994; Harding, *et al.,* 1993; Volkwein, *et al.,* 1994; and Gupta, *et al.,* 2000), and the transformation will obtain continuously methane resources (Guan, *et al.,* 1989). In Power River Basin of the United States, the total CBM yield is more than the exploration quantity (Pratt, *et al.,* 1999), indicating that the CBM resources produced by microbial action really cannot be ignored (Li, *et al.,* 1998). In all the low coal rank basins, the microbial methane more or less exists (Guan, *et al.,* 1997).[1]

However, the research about the mechanism of microbe increasing the permeability of coal reservoir is not still sufficient enough (Bouallagui, *et al.,* 2003; APHA, 1998; Dias, *et al.,* 2006). After systematically studying the CBM genesis in Sydney Basin, Apex Company in Australia put forward an idea of injecting the methane bacteria into the coal seam to stimulate the producing of biogenic gas and to increase the permeability of coal reservoir in the meantime. So far, permeability improvement of coal reservoir only has physical measures(Palmer, 2010), such as hydraulic fracturing and openhole cavity, but the low permeability problems of granulitic and mylonitic coal are still blocking the development of gas exploitation and CBM industry (Sang, *et al.,* 2010). The microbe can increase the permeability of coal reservoir by means of "eating

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off" the coal and transforming it into methane (Shao, *et al.,* 2006), which will improve the fracture number and width of coal reservoir. The smaller coal particle is, the more rapid microbe metabolizing will be, which suggests a new technique of increasing the permeability of coal reservoir is emerging. It has a significant influence on improving the yield of CBM well and the gas extraction effect of coal mine. The author chooses the middle-low rank coals as samples and compares some parameters before and after microbe acting on the coal samples, including the number and width of fracture, permeability and adsorption capacity, and finally finds out the mechanism and influence factors of microbial increasing the permeability of coal reservoir.

MATERIALS AND METHODS

Sample preparation

Fresh coal samples are collected from coal workface of underground mine and applied to the experiment (Fig. 1 and Table 1) .

Shaqu mine water is collected as the microbial strains source. To guarantee the anaerobic conditions, it is sealed immediately and sent to laboratory and preserved at 4° to keep the activity of microbial species.

Enriching method of microbial species: NH_4Cl 0.2 g, $K_2HPO_4 \cdot 3H_2O$ 0.4 g, KH_2PO_4 0.4 g, $CaCl_2$ 0.2 g, Yeast 1.0 g, $MgCl_2 \cdot 6H_2O$ 1.0 g, Tryptone 1.0 g, $C_3H_7NO_2S \cdot HCl$ 0.5 g, $C_6H_{12}O_6 \cdot H_2O$ 6.0 g, $C_{10}H_{14}N_2O_8Na_2 \cdot 2H_2O$ 1.0 g, coal mine drainage 1000 ml, all of them are mixed together and sealed in the electrothermal isothermal incubator at 35°.

Microscope observation

The fresh coal sample is cut and polished, and it is soaked into the mine water with microbial strains enrichment and sealed and placed in the thermostat for 10 days (Fig. 2). By microscope, surface characteristics of sample are observed respectively before and after microbial action.

As can be seen from the Fig. 2, the coal is degraded partly, forming some holes connecting each other on the coal surface, which is helpful to the migration and output of CBM. We compare the degradation of gas coal, fat coal and coking coal, the degradation of gas coal is apparently greater than coking coal. Under the same condition, low rank coal can be degraded more easily, while the degradation of high rank coal is weak.

Isothermal adsorption test

Firstly, the fresh coal sample of Shaqu mine is selected and ground to powder, then screen out 200 g with 60~80 mesh, and divide into two parts. The one part is soaked in the 500 ml mine drainage with microbial enrichment for 10 days,

Table 1. Coal sample analysis

Location of samples	coal seam	age	volatile %	moisture %	ash %	coal rank	$R_{o,max}$%
Quanling mine in Datong	No.23	P_1t	35.72	1.53	5.79	gas coal	0.74
Malan mine in Xishan	No.2	P_1s	27.69	0.58	6.71	fat coal	0.98
Shaqu mine in Liulin	No.4	P_1sh	22.31	2.09	8.32	coking coal	1.51

Table 2. The permeability before and after microbial action

location of sample	Coal sample No.	permeability of original sample(10^{-3} μm^2)	permeability of microbial action($10^{-3}\mu m^2$)	change rate (%)
Quanling mine	1	0.654	0.783	19.72
in Datong	2	0.812	1.047	28.94
	3	0.793	0.992	25.09
Malan mine	4	1.781	2.319	30.21
in Xishan	5	2.262	2.991	32.23
	6	1.614	2.057	27.45
Shaqu mine	7	2.327	2.975	27.85
in Liulin	8	1.264	1.497	18.43
	9	1.794	2.175	21.24

then is carried on centrifugation and drying. Isothermal adsorption experiment is conducted by the TerraTec IS-300 isothermal adsorption instrument made in America. The experiment conditions are: taking the methane with a purity of 99.99%, setting the maximum pressure to 8 MPa and 6 pressure points, setting 12 h adsorption equilibrium time for each point. In the test process, the computer can record the adsorption capacity of each pressure point automatically. The Langmuir volume and Langmuir pressure can be calculated and adsorption isothermal curve can be fitted based on the principle of Langmuir single molecular adsorption (Fig. 4).

Fig. 4 shows methane adsorption capacity of coal samples has enhanced significantly after microbiological degradation in the mine drainage, and surface area and porosity of coal have increased, which is favorable of the coal reservoir permeability. On the other hand, it shows the existence of microbial degradation for coal.

Permeability test

The study adopts the sample with ϕ50 mm×50 mm (Fig. 5). Experiment system includes sealed rubber sleeve, loading and unloading control machine, high pressure nitrogen, gas flow rate and gas pressure measure system (Fig. 6). Axial compression and confining pressure is 4 kN and 2 MPa respectively. The permeability of the sample can be calculated by the inlet pressure and the flow (Guo, *et al.,* 2010). Table 2 shows the results of the original and microbial action on coal samples for 30 days.

1-high pressure N_2; 2-gas regulator valve; 3-gas pressure sensor; 4-static resistance strain gauge, 5-data processing apparatus; 6-loads head, 7-Sealing rubber sleeve, 8-breathable panels, 9-coal sample; 10-gas mass flow meter, 11-gas flow totalizer, 12-data acquisition instrument

The permeability values of different samples have increased to different degrees after microbe acting on them, and in the same coal rank (Table 2), the higher the original permeability of coal reservoir is, the more obvious the effect of increasing the permeability is, suggesting that the effect of increasing the permeability is also related to the original permeability of the coal reservoir in addition to the coal rank factors. The main reason lies in the high permeability increasing the contact area of the coal and microbe, which is more conducive to the microbiological degradation.

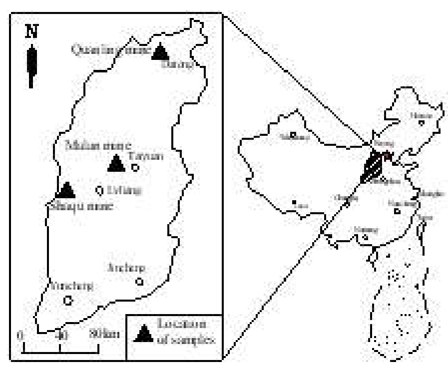


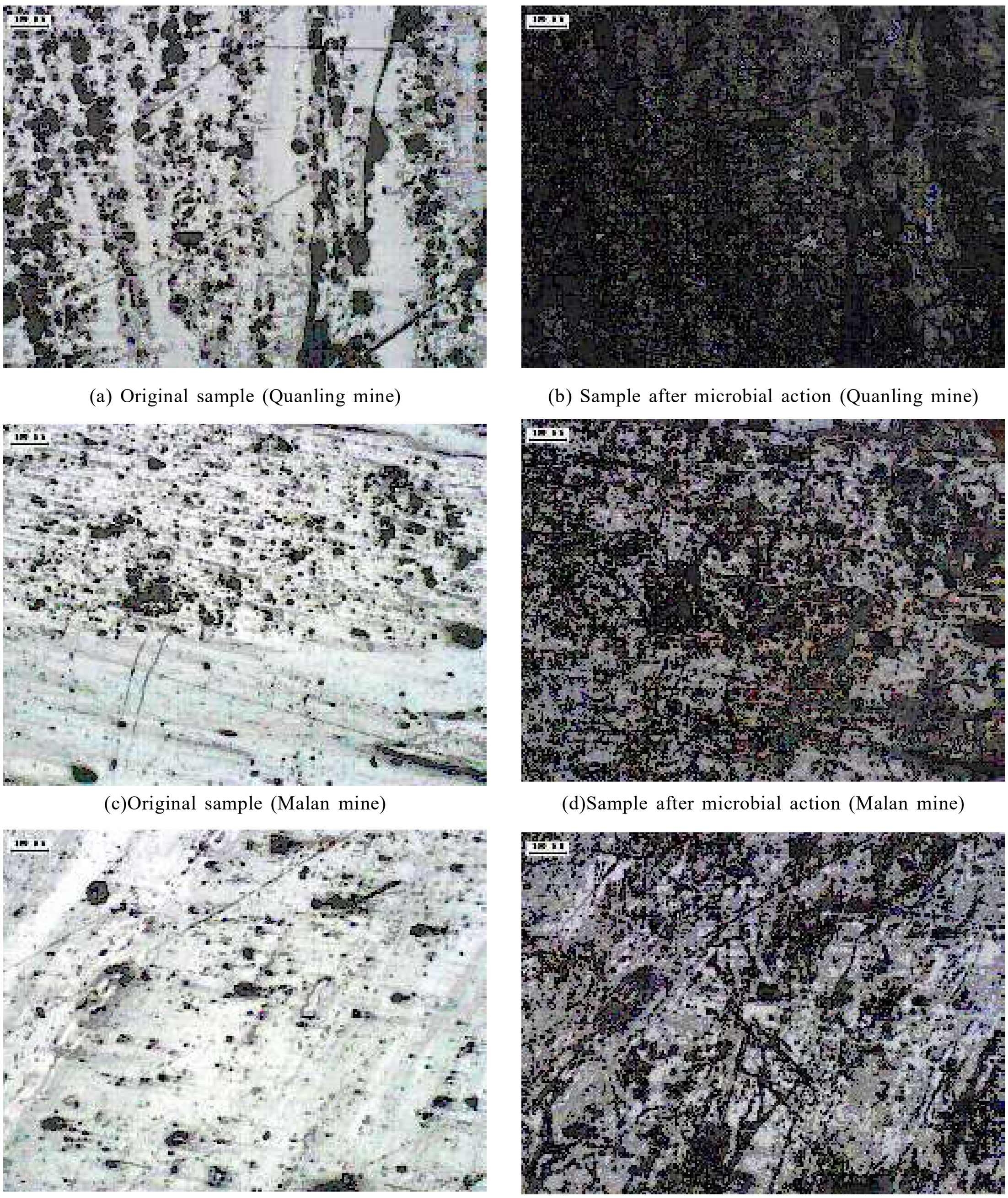
Fig. 1. Location of sample

Fig. 2. The coal samples and microbial action

The significance of increasing the coal seam permeability with microbial

The CBM development

The microbe not only can transform the coal into methane and increase the resource quantity of CBM in coal reservoir, but also can enhance the effect of microbe increasing the permeability, which is very significant for the CBM development. When developing the CBM, by means of injecting the microbial enrichment liquid into the coal seam, the yield and service life of a CBM extraction well will be improved notably with



(a) Original sample (Quanling mine)

(b) Sample after microbial action (Quanling mine)

(c)Original sample (Malan mine)

(d)Sample after microbial action (Malan mine)

(e)Original sample (Shaqu mine)

(f)Sample after microbial action (Shaqu mine)

Fig. 3. Surface characteristics of sample change after microbial action.

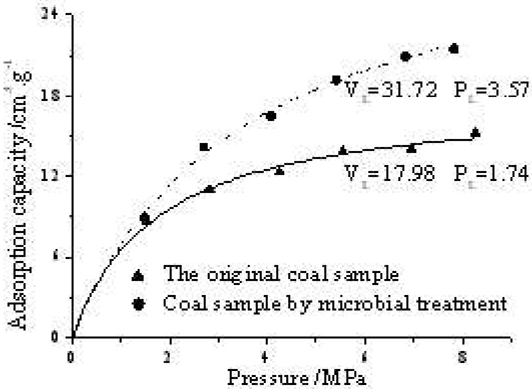


Fig. 4. Comparison to isothermal adsorption curve before and after microbial action

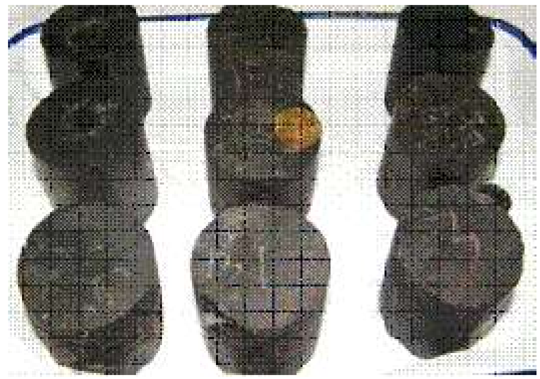


Fig. 5. The processed coal samples

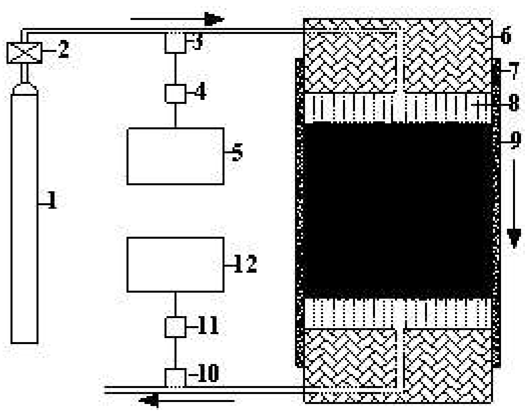


Fig. 6. The test system of permeability

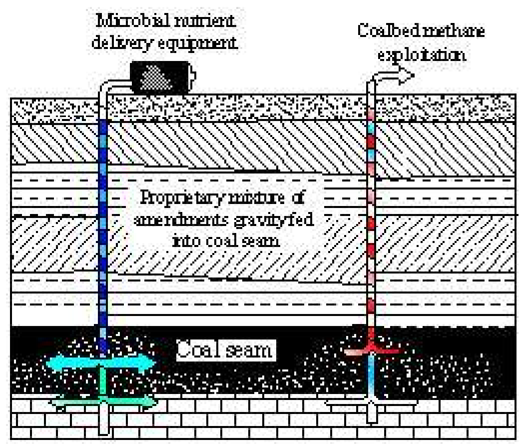


Fig. 7. CBM extraction model based on microbial technology

the lasting effect of microbe (Fig. 7).

The mine gas control

The gas is a main disaster in the safety production of coal mine, and it has caused a number of heavy casualties and property losses. In most cases, gas extraction is the main solution to this problem. However, the geological structure is very complicated and the development degree of the granulitic and mylonitic coal is quite common in China, which has the lower mechanical strength and the higher gas content and belongs to coal and gas outburst coal seam. Furthermore, when the permeability of coal reservoir is as low as 10^{-6}-10^{-7} im^2, the extraction radius is short, which results in the lower extraction rate and threatening the safety production of coal mine. Given that microbial action has such an effect of "eating off" the coal, if we inject suitable microbe enrichment liquid into the coal seams with high gas content and by means of the propagation of microbes to achieve the desired effect of increasing the permeability, so the extraction effect will be better and this technique will have a great application prospect.

CONCLUSIONS

- The microscope contrast observation confirms that the microbe can form some holes and increase the width and number of coal fracture, which raises the fracture interconnectivity of coal reservoir and contributes to the migration and output of CBM. At the same time, the lower coal metamorphic degree is, because of the coal with the low bonding degree of aromatic ring is easily destroyed by microbe, the more obvious the effect of increasing permeability is.

- Isothermal adsorption testing results show that methane adsorption capacity of the coal samples increases after microbial action, which indicates the biodegradation can improve the porosity and surface area of the coal. The permeability testing proves that the original permeability of coal reservoir is also another important factor influencing the effect of microbe increasing permeability. The reason is that the higher the original permeability of coal reservoirs is, the larger the contact area of coal and microbe is, which is in favor of the biodegradation and the effect of microbe increasing permeability.
- Biological increasing permeability of coal reservoir can not only increase the quantity of CBM resources, but also can improve the daily yield of CBM wells. Especially facing the current situation that the coal and gas outburst of the granulitic and mylonitic coal is severe and the method of hydraulic-fracturing can not be adopted, microbe increasing permeability has obvious advantages, and it provides a new way for coal mine gas control.

ACKNOWLEDGEMENTS

This study is funded by the National Science Foundation of China (No. 41002047 and No. 40972109), the Education Department of Henan Province Science and Technology research key project (No. 12A440005), the State Key Laboratory Cultivation Base for Gas Geology and Gas Control (Henan Polytechnic University) Open project (No. WS2012B05), Doctor Fund of Henan Polytechnic University (No. B2012-015).

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