ISSN 2616-5872 Vol.5, Issue 3: 7-12, DOI: 10.25236/AJEE.2023.050302

Summary of research methods for porosity and permeability of coalbed methane reservoir

Mao Fanjing[1,2], Lu Bingkun[1,2], Bai Qian[1,2]

[1]*School of Earth Sciences and Engineering, Xi'an Shiyou University, Xi'an, China*
[2]*Shaanxi Key Laboratory of Petroleum Accumulation Geology, Xi'an Shiyou University, Xi'an, China*
maofanjing424@163.com

Abstract: *In order to serve the research on the physical properties of coalbed methane reservoirs and improve the prediction effect of porosity and permeability of coal reservoirs, this paper, based on a large number of literature research, summarizes the concepts, influencing factors and prediction methods of coal seam porosity and permeability. The research shows that the main factors affecting the porosity of coalbed methane reservoir are coal petrographic composition, metamorphic degree, coal body structure and buried depth, compaction, tectonism, etc; The main influencing factors of permeability include component content, coal rank, coal body structure and in-situ stress, buried depth of coal seam, natural fracture of coal seam, matrix shrinkage, Klinkenberg effect, etc. The porosity prediction of coalbed methane reservoir generally adopts true and apparent relative density method, in addition, there are multiple regression method based on logging information, nuclear magnetic resonance logging method, etc; The measurement methods of CBM reservoir permeability mainly include the calculation method based on conventional logging, triaxial stress experimental research method, joint prediction method of nuclear magnetic resonance and electrical imaging logging, dynamic data analysis method and numerical simulation method. The development of coal seam porosity and permeability prediction technology needs innovative breakthroughs in hardware and software.*

Keywords: *Coalbed methane; Porosity; Permeability; Influencing factors; Prediction methods*

1. Introduction

The physical characteristics of coalbed methane reservoir directly determine the effect of coalbed methane storage and seepage. It is particularly important to strengthen the research on porosity and permeability of coalbed methane reservoirs for the exploration and development of coalbed methane. Therefore, many scholars focus on the physical properties of coalbed methane reservoirs. Wang Fujun et al. (2019) analyzed the permeability and key controlled factors of Dafosi low-rank coalbed methane reservoir; Huang Ting et al. (2019) studied and discussed the characteristics of coal reservoir pore structure and its influencing factors; Fu Yu et al. (2005) established a mathematical model of the influence of coal matrix shrinkage deformation on coal fracture permeability and porosity; Fu Xuehai et al. (2019) studied the differential characteristics of porosity, permeability and stress sensitivity of medium and high rank coal reservoirs under overburden conditions through experiments; Qin Yong et al. (2001) observed and counted the fractures of coal seams, calculated the areal density dimension and fractal dimension of pore volume of each grade of fractures in coal; Song Xiaozhong et al. (2011) analyzed and studied the pore characteristics of coal with different coal texture and structure through low-temperature liquid nitrogen adsorption test.

Previous research results provide a lot of basis for further research on porosity and permeability of coal seams, but most of them are based on special research on specific strata in specific areas. Based on a large number of literature research, this paper systematically analyzes and summarizes the influencing factors and prediction methods of the porosity and permeability of coalbed methane reservoirs, providing a more sufficient basis for the evaluation of coalbed methane reservoirs, and providing a reference for the exploration and development of coalbed methane and the safe production of coal mines.

2. Concept and influencing factors of porosity and permeability of coalbed methane reservoir

2.1 Concept of porosity and permeability of coalbed methane reservoir

(1) Concept of porosity of coalbed methane reservoir

Coal rock is a reservoir with dual pore structure, and its pore is divided into two types: bedrock pore and fracture pore [1]. CBM is stored in the pore system of coal body in the form of adsorption and in the fracture system in the form of dissociation. The main part of fracture pore refers to its endogenetic fracture, which is specially called cleat. It is two groups of micro-fractures developed in the process of diagenesis and evolution of coal rocks, which are roughly perpendicular to each other. Among them, the group with large extension length and developed is called face cleat; The other group that is crosscut by face cleats is called end cleats [2,3]. Luo Yingdu (1994) defined the pores of coal as the pores of coal. The pores of coal include the space occupied by water and the space occupied by air (or some kind of gas). The sum of them is the total pores of coal. Porosity is the percentage of the volume of these pores in the total volume of coal particles [4].

The vast majority of coalbed methane is stored in adsorption state in coal seams, and the pore structure characteristics directly affect the micro-physical and chemical processes of gas adsorption-desorption, diffusion and migration in coal reservoirs [5]. Therefore, studying the porosity of coal reservoirs is of great significance to the evaluation of favorable blocks for CBM exploration, the deployment of exploration projects and the selection of production processes [6].

(2) Concept of CBM reservoir permeability

The permeability of coalbed methane reservoir is mainly determined by the development degree of fractures (cleats or fractures) and controlled by the development degree of fractures and seepage holes, which is the main factor determining the flow of gas and water in the reservoir. Permeability of coalbed methane reservoir refers to the ability of coal rock to pass through coalbed methane under the effect of concentration difference. Permeability can reflect the seepage ability of coal and rock, and has a direct impact on the productivity of coalbed methane.

2.2 Influencing factors of coalbed methane reservoir porosity

The factors that affect the porosity of coalbed methane reservoir can be divided into internal and external factors. The internal factors mainly include coal metamorphism, coal petrographic composition and coal body structure; The external factors mainly include burial depth, compaction and tectonism. See Table 1 for its influence mechanism on the porosity of coalbed methane reservoir.

Table 1: Influencing factors and mechanism of porosity (according to literatures [5-10])

Influence factors		Impact mechanism	Literature sources
internal cause	Metamorphic degree	The micropore volume increases with the degree of metamorphism; The pore volume of the small hole increases slightly; The pore volume of the mesopore decreases first and then increases.	Huang Ting et al.
	Coal petrographic composition	The porosity of chitin is the most developed, followed by vitrinite and inertinite.	Zhang Hui et al.
	Coal structure	The porosity of cataclastic coal is greater than that of primary structural coal.	Huang Ting et al.
exopathic factors	Buried depth	Porosity decreases with the increase of burial depth.	Xu Qilu et al.
	Compaction	Porosity decreases with the increase of compaction.	Huang Ting et al.
	Tectonism	Fractures formed by tectonic action will increase reservoir porosity.	Shi Chaoqun et al.

2.3 Influencing factors of CBM reservoir permeability

The factors affecting the permeability of coal seams are very complex, which are often the result of the comprehensive action of multiple factors. The geological structure, stress state, buried depth of coal seams, coal body structure, coal quality characteristics of coal rocks, coal grades and natural fractures all affect the permeability of coal seams to varying degrees [11]. The internal factors that affect the permeability of coalbed methane reservoir mainly include component content, coal rank and coal body structure; External factors mainly include in-situ stress, buried depth of coal seams, natural fractures of coal seams, matrix shrinkage and Klinkenberg effect, as shown in Table 2.

Table 2: Influencing factors and mechanism of permeability (according to literatures [12-16])

Lnfluence factors		Impact mechanism	Literature sources
internal cause	Coal rank	The permeability decreases with the increase of coal grade, and the permeability of anthracite and lean coal is the lowest	Zhang Rui et al.
	Component content	The lower the ash content, the more developed the fractures and the higher the permeability; The higher the content of inertinite, the greater the permeability	Zhang Rui
	Coal structure	The permeability of primary structural coal and cataclastic coal is higher, and the higher the proportion of cataclastic coal and mylonite is, the lower the permeability is	Fu Xuehai et al.
external cause	In-situ stress	Permeability decreases with the increase of effective stress	Ye Jianping et al.
	Burial depth of coal seam	The greater the burial depth, the lower the permeability	Ye Jianping et al.
	Natural fracture of coal seam	The more developed the natural fractures, the higher the permeability	Qin Yong
	Matrix shrinkage	The matrix shrinks and the permeability increases	Zheng Han et al.
	Klinkenberg effect	Klinkenberg effect causes permeability increase	Li Peichao et al.

3. Prediction method of porosity and permeability of coalbed methane reservoir

3.1 Prediction method of coalbed methane reservoir porosity

(1) Laboratory determination of porosity of coal -- true and apparent relative density method

Chinese scholars and industry technicians generally calculate the porosity of coal according to the following formula by measuring the dry bulk density and true density of coal [17]:

$$n = (1 - \frac{\rho_g}{\rho}) \times 100\% \tag{1}$$

Where: n is the total porosity of coal,%; ρ_g is the dry bulk density of coal, g/cm^3; ρ is the true density of coal, g/cm^3.

Generally, the dry bulk density of coal is measured by sealing method or volumetric method, and the true density of coal is measured by pyknometer method or gas expansion method true density analyzer.

Lin Yongfu (1998) proposed that the true density and apparent density should be calculated based on the data obtained from the analytical basis when calculating the porosity of coal and rock using formula (1); If porosity is calculated by using the apparent density and true density measured directly in the laboratory, the calculated value will be higher [18].

(2) Multiple regression method based on logging information

Yu Zhaolin et al. (2020) established a multiple regression prediction model of coal reservoir porosity based on logging curves, taking the deep coal reservoir in Linxing area as the research object. The results show that the measured porosity has a positive correlation with acoustic transit time, natural gamma and borehole diameter, and a negative correlation with compensated neutron. Among them, the measured porosity has the best correlation with acoustic transit time, followed by compensated neutron. Compared with the porosity calculated by conventional density logging, the logging multiple regression prediction model of porosity has higher accuracy [19].

(3) Nuclear magnetic resonance logging

Yao Yanbin et al. (2010) proposed a new method for fine quantitative characterization of coal pore and fissure types, effective porosity, pore structure distribution and pore and fissure spatial configuration by using low-field nuclear magnetic resonance technology and micro-focus CT scanning technology [20].

Liang Xiao et al. (2017) analyzed the pore structure characteristics of coal reservoirs by nuclear magnetic resonance experiment, and obtained the fracture porosity of coal samples; The fracture porosity of coal reservoir is calculated by using the conventional resistivity logging method to evaluate the porosity of sandstone, and compared with the fracture porosity obtained by nuclear magnetic resonance experiment. It is found that the fracture porosity of coal reservoir obtained by the two resistivity methods has good consistency [21].

3.2 Prediction method of CBM reservoir permeability

(1) Calculation method based on conventional logging

The calculation methods of coal reservoir permeability based on conventional logging mainly include microresistivity logging, microelectrode logging, spontaneous potential logging and acoustic logging, among which microresistivity logging and microelectrode logging are more commonly used. Because of the linear relationship between resistivity and fracture porosity index, the permeability of coal seams can be determined by microresistivity logging. At present, the quantitative evaluation of coal reservoir permeability is mainly based on the calculation of coal seam fracture porosity by dual laterolog, and the correlation equation is obtained by using the crossplot technology, so as to obtain the coal reservoir fracture permeability [22].

(2) Experimental research method of triaxial stress

Triaxial stress experimental research method is the most commonly used method in the study of coal reservoir permeability. During the test, put the formed coal sample into the triaxial apparatus, connect the systems, and then synchronously apply the confining pressure and axial pressure to the specified value, keeping the confining pressure and axial pressure unchanged; Then slowly inject the gas into the sample, gradually reach the required gas pressure and stabilize, read the parameters, and use Darcy formula to calculate the permeability [22].

(3) Joint prediction method of nuclear magnetic resonance logging and electrical imaging logging

Ping Haitao et al. (2020), referring to the permeability calculation method of nuclear magnetic resonance logging, extended the permeability calculation model of nuclear magnetic resonance logging reservoir to the electrical imaging porosity spectrum, and proposed a complex reservoir permeability model based on the electrical imaging porosity spectrum [23]:

$$K_{SDR}{}^{*} = C * \left(\frac{\phi}{100}\right)^{4} * P_{2\mathrm{gm}}{}^{2} \tag{2}$$

In the formula, C is the regional experience coefficient, 200; φ is the porosity of the formation; P_{2gm} is the geometric mean value of the electrical imaging porosity spectrum. The permeability calculated by electrical imaging porosity is well correlated with that calculated by nuclear magnetic resonance logging.

(4) Dynamic data analysis method

Based on the "matchstick" concept model, Tang Dazhen et al. used the material and energy dynamic balance method to predict the reservoir pressure and water saturation, and established a permeability evaluation model for high-rank coal reservoirs based on the PMG absolute permeability model and the CPL relative permeability model [24,25]. Xia Peng et al. established the permeability evaluation model of middling coal rank coal reservoir through the dynamic balance theory of material and energy, and explained the dynamic change characteristics and control mechanism of coal reservoir permeability in different drainage stages of middling coal rank CBM wells from the aspects of permeability change trend, dominant mechanism, productivity dynamics [26,27].

(5) Numerical simulation method

Chen Zhenhong and others carried out numerical simulation of dynamic changes of coal reservoir permeability based on the data of No. 3 coal reservoir of Xiashan Formation in Fanzhuang Block, Qinshui Coal Seam Gas Field. The simulation results show that the reservoir permeability changes in an asymmetric "U" shape during the development process, and the physical property of middling coal reservoir decreases first and then increases during the development process [28,29].

4. Conclusion

(1) The main factors affecting the porosity of coalbed methane reservoir are coal metamorphism, coal petrographic composition, coal body structure and burial depth, compaction and tectonism; The main influencing factors of permeability are coal rank, component content, coal body structure and in-situ stress, buried depth of coal seam, natural fracture of coal seam, matrix shrinkage, Klinkenberg effect, etc.

(2) The porosity of coalbed methane reservoir is generally measured by the true and apparent relative density method in the laboratory. In addition, there are multiple regression method based on logging information, nuclear magnetic resonance logging method and dynamic data analysis method; The measurement methods of CBM reservoir permeability mainly include the calculation method based on conventional logging (mainly using dual laterolog method), triaxial stress experimental research method, organic combination of nuclear magnetic resonance logging and electrical imaging logging, dynamic data analysis method and numerical simulation method.

(3) The porosity and permeability of coalbed methane reservoir are comprehensively affected by many factors, and a single measurement method cannot accurately and quantitatively estimate. Therefore, the prediction of the porosity and permeability of coalbed methane reservoir should be based on the petrophysical experiment, determine the logging information sensitive to the porosity and permeability of coalbed methane reservoir, and use nonlinear mathematical methods to achieve multi-information fusion to improve the prediction accuracy of the porosity and permeability of coalbed methane reservoir; At the same time, facing up to the shortcomings of traditional logging methods for dynamic parameter measurement, it is worth paying attention to the design of logging technology that can measure dynamic parameter permeability.

References

[1] Zhao Junlong, Chi Jiawei. Review and prospect of factors affecting the physical properties of coalbed methane reservoirs and prediction methods [J]. Progress in Geophysics, 2020, 35 (01): 272-280
[2] Hou Junsheng. Coal bed gas reservoir logging evaluation method and its application [M]. Metallurgical Industry Press, 2000
[3] Hou Ruiyun. Characteristics of porosity and relative permeability of coal reservoirs and their measurement methods [J]. Petroleum Experimental Geology, 1996
[4] Luo Yingdu, Zhu Chunsheng. How to correctly calculate the porosity of coal [J]. Coal Quality Technology, 1994 (04): 30-36
[5] Huang Ting, Liu Zheng. Analysis of pore structure characteristics and influencing factors of massive coal reservoirs in Yushe-Wuxiang area [J]. Coal Science and Technology, 2019, 47 (07): 227-233
[6] Wang Mingshou, Tang Dazhen, Zhang Shanghu. Research status and significance of coal reservoir porosity [J]. China Coalbed Methane, 2004
[7] Zhang Hui. Genetic types of coal pores and their research [J]. Journal of Coal, 2001 (01): 40-44
[8] Xu Qilu, Huang Wenhui, Tang Shuheng, et al. Pore structure and adsorption of deep medium-high coal reservoirs [J]. Modern Geology, 2016, 30 (02): 413-419
[9] Huang Qiang, Fu Xuehai, Zhang Qinghui, et al. Research on overburden porosity and permeability test of medium-high rank coal reservoirs in Qinshui Basin [J]. Coal Science and Technology, 2019, 47 (06): 164-170
[10] Shi Chaoqun, Xu Anming, Wei Hongxing, Hu Chunlei, Zhang Xing, Zhang Wen, Mo Tao, Zhang Huifang, Zhou Lu, Shi Lingling, Zhu Wenhui, Chen Weili. Quantitative characterization of the damage degree of tectonic compression to clastic rock reservoirs - taking the Jurassic Ahe Formation of the Ikyk structural belt in the Kuqa depression as an example [J]. Journal of Petroleum, 2020, 41 (02): 205-215
[11] Ye Jianping, Shi Baosheng, Zhang Chuncai. Permeability of coal reservoirs in China and its main influencing factors [J]. Journal of Coal, 1999, (02): 3-5
[12] Zhang Rui. Research on logging evaluation method of coalbed methane reservoir [D]. Jilin

ISSN 2616-5872 Vol.5, Issue 3: 7-12, DOI: 10.25236/AJEE.2023.050302

University, 2016
[13] Fu Xuehai, Jiang Bo, Qin Yong, et al. Use logging curves to divide coal body structure and predict coal reservoir permeability [J]. Logging Technology, 2003 (02): 140-143+177
[14] Qin Yong. Research progress and analysis of coalbed methane genesis and reservoir physical properties abroad [J]. Geoscience Front, 2005 (03): 289-298
[15] Zheng Han, Liu Kaide, Li Xiaolong, et al. Research progress on pore and fracture structure and permeability of coal reservoirs based on NMR and CT [J]. Science and Technology Innovation, 2020, (34): 64-67
[16] Li Peichao, Kong Xiangyan, Zeng Qinghong, et al. Summary and analysis of factors affecting coal seam permeability [J]. Natural Gas Industry, 2002, (05): 45-49+8-7
[17] Guo Heng. Research progress of coal porosity measurement method [J]. Energy Technology and Management, 2018, 43 (01): 1-3
[18] Lin Yongfu. Also on the formula for calculating the porosity of coal with true and apparent relative density [J]. Guangxi Coal, 1998, 16 (4): 36-37
[19] Yu Zhaolin, Wang Yanbin, Yu Yun, et al. Deep coal reservoir porosity logging prediction model based on multiple regression [J]. Inner Mongolia Coal Economy, 2020 (01): 24-25
[20] Yao Yanbin, Liu Daman, Cai Yidong, et al. Fine quantitative characterization of pores and fractures of coal based on NMR and X-CT [J]. Science of China: Earth Science, 2010, 40 (11): 1598-1607
[21] Liang Xiao, Wang Shan, Zhou Mingshun, et al. Evaluation of coal reservoir porosity based on nuclear magnetic resonance and resistivity logging [J]. Coal Engineering, 2017, 49 (08): 130-133
[22] Bo Dongmei, Zhao Yongjun, Jiang Lin. Research methods and main influencing factors of coal reservoir permeability [J]. Oil and Gas Geology and Recovery, 2008 (01): 18-21+112
[23] Ping Haitao, Qin Ruibao, Sun Jianmeng, et al. Porosity spectrum analysis of electrical imaging logging and its application in permeability evaluation of complex reservoirs [J/OL]. Geophysical progress, 2020 (12):1-9
[24] Tang Dazhen, Zhao Junlong, Xu Hao, Li Zhiping, Tao Shu, Li Song. Material and energy dynamic balance mechanism of medium-high rank coalbed methane system [J]. Journal of Coal, 2016, 41 (01): 40-48
[25] Xia Peng, Zeng Fangui, Wu Jing, Wang Jin, Feng Shaosheng. Division of drainage and production stages and permeability changes of middling coal rank coalbed methane wells [J]. Journal of Southwest Petroleum University (Natural Science Edition), 2018, 40 (06): 115-123
[26] Chen Zhenhong, Chen Yanpeng, Yang Jiaosheng, et al. Dynamic permeability characteristics of high-rank coalbed methane reservoir and its impact on coalbed methane production [J]. Journal of Petroleum, 2010, 31 (06): 966-969+974
[27] Wang Fujun, Zhang Yachao, Dou Chengyi, et al. Analysis of permeability and key controlled factors of Dafosi low-rank coal-gas reservoir [J]. Coal Mine Safety, 2019, 50 (11): 154-157
[28] Fu Yu, Guo Xiao, Jia Ying, et al. A new mathematical model for the effect of coal matrix shrinkage on fracture permeability [J]. Natural Gas Industry, 2005, (02): 143-145+218
[29] Zhang Yao, Zhao Junlong. Identification of coal body structure based on geo physical logging and its impact on CBM mining [J]. Mineral Exploration, 2020, 11 (10): 2194-2200