Recommended Practice for Experimental Evaluation of the Seepage Sensitivity Damage of Coalbed Methane Reservoirs

Hao Liu, Lihui Zheng, Chinedu J. Okere, Chao Wang, Xiangchun Wang, Peng Zhang

Abstract—The coalbed methane (CBM) extraction industry (an unconventional energy source) has not established guidelines for experimental evaluation of sensitivity damage for coal samples. The existing experimental process of previous researches mainly followed the industry standard for conventional oil and gas reservoirs (CIS). However, the existing evaluation method ignores certain critical differences between CBM reservoirs and conventional reservoirs, which could inevitably result in an inaccurate evaluation of sensitivity damage and, eventually, poor decisions regarding the formulation of formation damage prevention measures. In this study, we propose improved experimental guidelines for evaluating seepage sensitivity damage of CBM reservoirs by leveraging on the shortcomings of the existing methods. The proposed method was established via a theoretical analysis of the main drawbacks of the existing methods and validated through comparative experiments. The results show that the proposed evaluation technique provided reliable experimental results that can better reflect actual reservoir conditions and correctly guide the future development of CBM reservoirs. This study is pioneering the research on the optimization of experimental parameters for efficient exploration and development of CBM reservoirs.

Keywords—Coalbed methane, formation damage, permeability, unconventional energy source.

I. INTRODUCTION

IN recent decades, unconventional energy sources have increasingly become the world's primary source of fossil fuels. To meet the global energy demand and environmental concerns, more CBM reservoirs are continually exploited [1]. CBM is an unconventional energy source that supplies clean, high-quality, and efficient energy resources with a wide variety of applications [1]. The development and utilization of CBM have attracted the attention of several field experts and scholars around the world [2], [3]. Additionally, with the recent global sensitization and awareness on environmental protection and the introduction of increasingly stringent environmental policies, the exploration and development of CBM reservoirs have become one of the main focuses of the energy industry. However, studies have shown that the development of CBM reservoirs has suffered a significant setback due to its complicated reservoir characteristics such as the existence of endogenetic fractures (cleats) with mainly clay minerals composition and medium to small pore-throats, which often leads to reservoir damage during field operations (e.g., drilling, completion, workover, stimulation, mining, and so on), and eventually decline in the recovery of energy resources [4]. In general, sensitivity damage evaluation (involving water, salt, acid, alkali, velocity, etc. sensitivity damage) is the commonly used approach in estimating the degree of reservoir damage in the petroleum industry for an effective development strategy that will enhance reservoir protection and the prevention of formation damage.

At present, the conventional sensitivity evaluation approach for CBM reservoirs is based on China's industry-standard (SY/T 5358-2010) for "experimental evaluation method of reservoir sensitivity flow" [5]. However, the limitations for applying the conventional industry standard (CIS) in the sensitivity evaluation of CBM reservoirs are explained as follows: (1) A major criterion for applying the aforementioned industry standard is that the gas permeability should be greater than $1 \times 10^{-3} \ \mu m^2$. However, the air permeability of coal seams is generally lower than $1 \times 10^{-3} \ \mu m^2$. (2) The CIS method mainly uses liquid as the test medium, but in actual conditions, CBM reservoirs often involve a multi-phase fluid flow with gas as the dominant phase. (3) The pressure differential and surface frictional effects between a liquid and gaseous phase, some phenomena such as viscous resistance and slippage effect often influence fluid flow characteristics; hence, using liquid to carry out gas reservoir sensitivity evaluation experiment could result in the defects of high displacement pressure, long test time and large data error. Therefore, the above limitations could significantly affect the experimental results which cannot reflect the real state of gas reservoirs (especially after reservoir damage). Thus, it is significant to develop an alternative approach for laboratory sensitivity evaluation of CBM reservoirs. On the other hand, some scholars have attempted to overcome these limitations by improving and optimizing experimental preparation methods, procedures, equipment, and conditions [6]-[10]. It is important to note that, except for cases such as water/salt sensitivity, acid sensitivity, and alkali sensitivity where a liquid phase must be involved, other sensitivity evaluation experiments use nitrogen as the test medium.

Although the proposed approach by the above scholars has optimized the application of the industry-standard method to some extent and expanded the scope of application, however, the analysis of previous studies was not in-depth enough, as key areas such as coal sample preparation were ignored [11], the

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experimental parameters setting was mostly empirical and lacked an effective theoretical basis [12], [13]. Therefore, this study aimed at proposing efficient laboratory practices for the experimental evaluation of sensitivity damage of CBM reservoirs, by leveraging on the shortcomings of the existing methods. Further, the challenges of the existing sensitivity evaluation systems were theoretically analyzed. Based on the theoretical analysis, a sensitivity evaluation scheme was formulated for CBM reservoirs. The feasibility of the method was validated by comparing the experimental results with the CIS method.

II. Main Drawbacks of Existing Methods

A. The Ineffective Sample Preparation Technique

Proper coal sample preparation (cleaning, drying, saturation, etc.) is the premise of carrying out a sensitivity evaluation experiment and ensuring the accuracy of data analysis. Unlike clastic rocks, coal rocks are composed of high content of organic matter. If the cleaning solvent for sandstone and carbonate rock that was specified by the CIS code of practice (GB/T 29172-2012) for the core analysis is used to treat coal samples, the organic components in the coal seam may be dissolved. Furthermore, the microstructural components of the rock particles in coal seams are loose with poor cementation; hence an improper selection of cleaning solvent could weaken the cementation of coal and rock particles, leading to loosening and collapse of the core which will inevitably induce further damage to the core sample. Similarly, for the drying process of coal samples, the minimum drying temperature of sandstone and carbonate rock is 90 °C as specified in GB/T 29172-2012, if coal samples are also processed according to this standard, it is likely that the internal structure of the core will be damaged and the mineral composition of the core will be significantly altered due to the impact of excessive temperature on coal matrix. While referring to other high-clay rocks with a maximum drying temperature of 60 °C as specified in GB/T 29172-2012 to process coal samples, the residual liquid inside the coal may not be completely removed due to too low temperature; hence, it will be inappropriate to successfully dry the core sample during the experiment.

Hydrological condition is one of the main control factors for CBM enrichment and high-yield potential [11]. Under the condition of the original water saturation of the reservoir, the initial permeability measured can truly reflect the seepage characteristics of the reservoir. At present, the CIS does not explicitly recommend a method for establishing the water saturation of coal and rock. Generally speaking, the CIS mainly refers to conventional clastic rock samples, including its drying method, centrifugal method, and displacement method. However, the drying method (or air-drying method) often results in the salinity of core water being higher than that of formation water, and the distribution of core water is not uniform because the water volatilization extends from the outer circumference of the core plug to the inner part. Also, it is difficult to determine a reasonable rotation speed of the centrifuge by the centrifugal method. If the rotation speed of

centrifugal dehydration is too large, the core structure may collapse owing to its poor cementation; the gas displacement method itself cannot obtain sub irreducible water saturation, which cannot meet the needs of ultra-low water saturation in the formation. Because of the limitations of the CIS method in establishing sub-bound water saturation, a capillary spontaneous imbibition method was proposed by different scholars for low permeability rock samples [15], [16]. However, the capillary self-priming method is still relatively time-consuming, and it is not easy to control the water saturation, which greatly affects the accuracy of data.

B. The Significant Variation between Experimental and Field Conditions

The research results of the laboratory have not been well applied to the field to guide the optimization of engineering operation parameters. An important reason is that the simulation conditions and measurement results of the laboratory have not been converted into reservoir conditions so that the conclusions are only transferred to the laboratory. The CIS code (SY/T 5358-2010) for either measuring the initial permeability of core samples or performing other types of experiments, has a large gap between the set experimental conditions and the real gas reservoir environment. There are two specific variations in experimental and field conditions; first, the confining pressure and core pore pressure in the experiment are too low [12], which is inconsistent with the actual formation of rock creep characteristics, and cannot reflect the change of coal seam permeability under in-situ stress. Second, in actual production, there is a back pressure at the end of the nozzle. However, in the laboratory evaluation via the CIS method, there is no back pressure at the outlet end of the core holder, as it is directly connected with the atmosphere. Hence, the pore pressure at the outlet end is treated as 0 MPa. The negative impact of the above drawbacks can be summarized in three points: (1) The change mode of core net stress can only adopt the change of confining pressure, which is inconsistent with the actual situation of a gas reservoir. (2) The rock mass structure near the outlet end of the core holder is subject to large effective stress, which makes the outlet end of the core more prone to stress sensitivity than the inlet end, which affects the accuracy of the experimental data. (3) The difference between the inlet and outlet pressures of the core is large. Due to the strong compressibility of the gas, the flow rate through the inlet and outlet ends of the core is different. The flow rate data obtained are not the real flow rate under the average pore pressure of the formation, which greatly reduces the reference value of the experimental results.

C. The Negative Impact of Slippage Effect

The pore throat of CBM is small and the micropore is extremely developed; when the gas below a certain pressure flows through the inner channel of the core and percolates at a low speed, the flow phenomenon deviates from Darcy's law because the gas does not produce an adsorbed thin layer on the wall of the seepage channel (slippage effect). In addition, the velocity of gas molecules has no obvious difference between

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the center of the channel and the wall of the channel. Therefore, at this point, the measured permeability is greater than the absolute permeability, which will significantly affect the accuracy of experimental results of reservoir sensitivity evaluation. To overcome the negative effect of the slippage effect, the correction formula of gas logging permeability and absolute permeability established by Klinkenberg is generally adopted; that is, the permeability of the core is tested at different pressure points, and the Klinkenberg permeability of the core is obtained through permeability correction. However, in the process of sensitivity evaluation, this method will lead to a complex evaluation process and inconvenient operation.

III. RECOMMENDATIONS FOR IMPROVED SENSITIVITY EVALUATION EXPERIMENTS

A. Optimization of Sample Preparation Technique

The techniques adopted by most recent studies on the experimental evaluation of sensitivity damage were based on subsequent sensitivity tests (which neglects the pretreatment process), and only a few studies focus on the sample pretreatment in the early stage of the experiment [6], [8], [10]. Therefore, in subsequent sections, we highlight an improved sequence of core sample preparation that accounts for the combination of the CISs (SY/T 5358-2010 and GB/T 29172-2012), and the characteristics of the CBM reservoir.

1. Optimization of Cleaning Solvent

It is necessary to remove all the original fluid or residual impurities before the sensitivity evaluation experiment. GB/T 29172-2012 highlights over ten kinds of hydrocarbon solvents for conventional cores and eight of them are selected theoretically. Through the cleaning medium contrast experiment on coal samples, the appropriate cleaning solvent is selected based on the criteria of no falling block, particle, or powder residue in the cleaning process and the maximum change of core mass before and after cleaning. See Table I for the rate of change of core mass of coal samples before and after cleaning with eight solvents.

As Table I indicates, only methanol, benzene, and benzene + methanol do not damage the rock mass structure. Furthermore, the rate of change of the mass of coal samples cleaned by the three cleaning agents from low to high follows the order: benzene < methanol < benzene + methanol, indicating that a mixture of benzene and methanol solvent can effectively remove the residual liquid and salt crystal impurities in coal samples. Therefore, benzene + methanol is the recommended cleaning solvent for coal samples.

2. Optimization of Drying Temperature

After the sample is cleaned, the residual solvent in the core needs to be dried to avoid interference with subsequent experiments. For this reason, a total of eight groups of comparative experiments under different drying temperatures between 50 °C and 120 °C were carried out for coal samples. The drying time was not more than 4 hrs. Based on the fact that there was no falling block, particle, or powder residue during the drying process with a minimal rate of change of the mass of

coal samples before and after drying, an optimal drying temperature or temperature range for coal samples was established. The rate of change of the mass of coal samples and the experimental phenomena under different drying temperatures are shown in Table II.

TABLE I
EFFECT OF DIFFERENT CLEANING SOLVENTS ON COAL SAMPLE TREATMENT

Cleaning Solvent	Mass before Cleaning (g)	Mass after Cleaning (g)	Rate of Change in Mass (%)	Cleaning Phenomenon
acetone	37.73	36.51	3.23	falling granular residue
methanol	38.29	37.96	0.86	no damage to the core
chloroform + methanol	38.37	37.62	1.95	drop powdery residue
dichloromethane	39.16	35.44	9.50	falling lump residue
oxacyclopentane	40.05	37.70	5.87	falling granular residue
benzene	39.81	39.56	0.63	no damage to the core
benzene + methanol	37.04	36.64	1.08	no damage to the core
ethylene chloride	37.52	34.83	7.17	falling lump residue

TABLE II
EFFECT OF COAL SAMPLE TREATMENT UNDER DIFFERENT DRYING TEMPERATURE

Drying Temperature (°C)	Mass before Cleaning (g)	Mass after Cleaning (g)	Rate of Change in Mass (%)	Experimental Phenomenon
50	41.05	40.38	1.63	no damage to the core
60	40.58	39.71	2.14	no damage to the core
70	39.65	38.53	2.82	no damage to the core
80	37.92	36.72	3.16	there is a small amount of powdery residue
90	38.76	36.96	4.64	falling granular residue
100	40.47	38.40	5.11	falling granular residue
110	38.34	35.66	6.99	the surface is slightly cracked and the granular residue is dropped
120	39.11	36.04	7.85	surface cracking, falling massive residue

Table II shows that when the drying temperature is about 70 °C, the rate of change of the mass of coal samples reaches the maximum value under the condition that the coal structure is not damaged, indicating that the residual cleaning solvent in the rock core has been removed by evaporation at this temperature. Therefore, the recommended drying temperature of the coal sample should not exceed 70 °C.

3. Optimization of Irreducible Water Saturation

CBM reservoirs are generally water-rich. Hence, before the sensitivity damage evaluation experiment, it is necessary to simulate the actual situation of the formation and establish the original water saturation of the reservoir. As mentioned in the previous section, several scholars have explained the shortcomings of several common methods in the process of establishing water saturation [11], [16], [17]. Comparatively speaking, the advantages of the capillary self-absorption method are more prominent. Its disadvantages are that it takes

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more time and the distribution of the self-absorption phase is not uniform enough, and the centrifugal method can make up for these two defects. For this reason, the comparative experiments of the drying method, centrifugal method, displacement method, capillary self-priming method, and capillary self-priming method + centrifugal method were carried out. It was assumed that the initial water saturation of the gas reservoir was 10%, and the time needed to establish the saturation and the actual water saturation value was the optimizing criteria. It was assumed that the initial water saturation of the gas reservoir was 10%, the time needed to establish this saturation and the actual water saturation value were used as the evaluation criteria to compare the effect of the above five methods to establish water saturation, so as to select the best saturation establishment method suitable for coal samples. The comparative experimental data of the five water saturation establishment methods are shown in Table III, and the equation for calculating the water saturation of rock samples is shown in (1):

$$S_w = \frac{4(m_w - m_o)}{\pi d^2 L \rho} \times 100\% \quad (1)$$

where, m_w and m_o are the mass of saturated and dry coal samples respectively g; d is the core diameter, cm; L is core length, cm; and ρ is the density of the saturated core, g/cm^3.

TABLE III
COMPARISON OF FIVE METHODS FOR ESTABLISHING WATER SATURATION OF SATURATED COAL SAMPLES

Established Method of Water Saturation	Core Diameter (cm)	Core Length (cm)	Mass before Saturation (g)	Mass after Saturation (g)	Water Saturation (S_w/%)	Time (h)
drying (or air drying)	2.51	5.49	39.68	42.55	10.07	>18
centrifugation	2.54	5.36	39.22	42.14	10.24	<3
displacement	2.51	5.64	40.31	44.97	15.91	>16
capillary self-absorption	2.48	5.49	36.62	39.42	10.06	<8
capillary self-absorption + centrifugation	2.53	5.27	37.17	39.98	10.11	<6

Table III shows that the water saturation established by the displacement method was 5.91% higher than the specified value, and the deviation was large, which indicates that it cannot establish the irreducible water saturation for low permeability cores, and it is suitable for establishing irreducible water saturation for high and medium permeability cores. The drying method (or air-drying method) takes too long, reaching more than 18 hrs. The centrifugal method takes the shortest time, but the accuracy of establishing water saturation is not easy to control. There is still a gap of 0.24% between this experiment and the standard value, and it is difficult to determine the rotation speed of the centrifuge when the centrifugal method is used alone. Furthermore, the operation of the capillary self-absorption method is a little cumbersome and time-consuming, which is close to 8 hours. The combination of the capillary self-absorption method and centrifugal method is less time-consuming and efficient, which not only makes up for the

difficulty in determining the rotation speed of the centrifugal method but also shortens the time of the capillary self-absorption method. Therefore, it is recommended that the self-absorption method + centrifugation method is suitable for establishing irreducible water saturation of coal samples.

B. Optimization of Experimental Conditions by the Equivalence Principle

Because of the large gap between the laboratory simulation conditions and the actual gas reservoir, scholars have made appropriate improvements based on experience. Reference [13] thought that the buried depth of the coal seam was generally shallow, and the effective stress was generally between 6 MPa and 8 MPa, so the confining pressure was adjusted to 6 MPa in the experiment. According to the coal sample depth of 300-500 m, [14] estimated the net confining pressure of 4 MPa as constant effective stress for velocity sensitivity experiment. Reference [15] directly selected the actual formation pressure parameters and set the effective stress of 31.25 MPa for core samples at the depth of 2500 m to improve the degree of accuracy during the stress sensitivity experiment and to simulate the field reservoir. However, the setting of experimental parameters in the above studies is still questionable. This is because the stress applied to the core ignores the force shared by the rock skeleton in the formation and the fluid in the pores. Compared with the actual reservoir, the rock sample used in the experiment is only a tiny unit, and the force cannot be completely equal to or close to the actual overlying pressure of the formation. Therefore, the measured results, in this case, are inevitably biased. To solve this problem, we assume that the percolation capacity of the gas reservoir and rock sample is similar or equal, and then use the average permeability data obtained from logging and well testing to convert the initial gas flow of the experimental rock sample, then finds out the reasonable equivalent confining pressure through debugging. See (2) and (3) for gas flow conversion:

$$K_f = K_i \quad (2)$$

$$Q = \frac{(p_1^2 - p_2^2) K_i A}{2 p_0 \mu L} \times 10^{-2} \quad (3)$$

where; K_f and K_i are the permeability of the actual reservoir and core samples respectively, 10^{-3} μm^2; Q is the gas flow rate through the core, cm^3/s; p_1 and p_2 are the core inlet and outlet pressure respectively, MPa; A is the cross-sectional area of the rock sample, cm^2; p_o is standard atmospheric pressure under test conditions, MPa; μ is the viscosity of fluid under test conditions, MPa/ s; and L is the core length, cm.

The specific steps to determine the confining pressure are as follows: (1) The pore pressure of the core is the same as that of the original reservoir, that is, both the inlet pressure and the outlet back pressure of the core are set as the reservoir pressure. (2) Based on the equivalence principle, the permeability of the core samples in reservoir and laboratory conditions are, therefore, the corresponding flow rate value or interval can be calculated. (3) When the flow through the core sample follows

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the flow value or interval calculated in step 2, and the difference between the confining pressure and the pressure of the core per depth (0.02264 MPa/m) is not more than 8 MPa, it is considered that the confining pressure at this time is the equivalent confining pressure.

C. Optimization of Experimental Parameters to Eliminate Slippage Effect

Reference [16] suggested that the slippage effect gradually weakens with the increase of rock pore pressure and the impact of slippage effect on permeability under reservoir pressure conditions is negligible. Reference [17] further explained that the slippage effect could be eliminated by exerting a back pressure which exceeds limit (or critical) pressure when measuring the gas permeability of rock samples, and the accuracy of rock permeability can be improved. Reference [18] proposed that the back pressure should be applied at the outlet of the core to better simulate the flow behavior of gas production in downhole and near-well reservoir, so that the fluid near the outlet is also pressurized ahead of time, which could increase the pressure transmission efficiency and decrease the influence of slippage effect on the experimental results. Hence, in section II, we established that it is not only the back pressure that is applied at the outlet of the core but also the inlet and outlet pressures of the core that are consistent with the original reservoir pressure. This implies that the average pore pressure and the back pressure of the experimental core are high, so the influence of the slippage effect can be ignored. In addition, the attraction between gas and water molecules is much greater than that of gas and solid under the condition of predominant water content [19]. Because the coal seam is usually rich in formation water, before the sensitivity evaluation experiment, it is necessary to establish the original water saturation of the reservoir on the core, which can also eliminate the slippage effect of the gas. Therefore, under the experimental parameters set in this paper, there is no need to worry about the influence of the slippage effect on the experimental results.

V. VALIDATION OF RECOMMENDED PRACTICES VIA COMPARATIVE ANALYSIS OF EXPERIMENTAL DATA

In this section, we performed velocity sensitivity and stress sensitivity experiments using the CIS method (SY/T 5358-2010) and the improved sensitivity evaluation method that is based on the recommended practices in this study to verify the rationality of the improved method. The comparative experimental results of velocity sensitivity and stress sensitivity are presented in Figs. 1 and 2, respectively. The corresponding seepage velocity is calculated using (4) and (5):

$$v = \frac{14.4 Q_m}{A\varphi} \qquad (4)$$

$$\eta = \frac{K_n}{K_o} \times 100\% \qquad (5)$$

where; v represents the fluid seepage velocity, m·d^{-1}; Q_m is the flowrate, cm^3·min^{-1}; φ is the porosity of the core sample, η is the permeability ratio of core samples at different flow rates; K_o

is the initial permeability (permeability of rock sample corresponding to the minimum flow rate in the experiment), 10^{-3} μm^2; and K_n is the permeability of the core sample (corresponding to different velocities in the experiment), 10^{-3} μm^2.
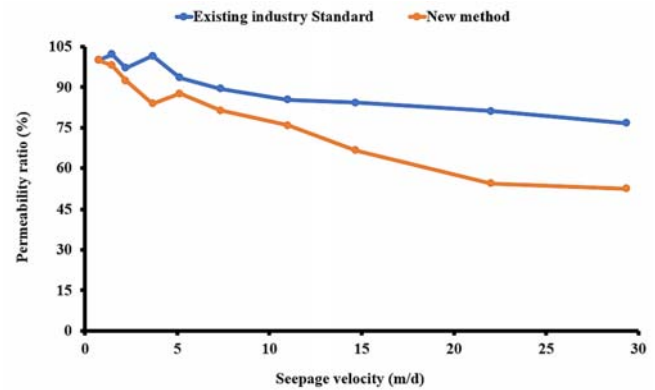

Fig. 1 Experimental results of velocity sensitivity by CIS and the proposed method

Comparing the results of the velocity sensitivity experiment in Fig. 1, it can be seen that the overall damage degree of the proposed method is higher than that of the CIS method. Herein, the velocity sensitivity index obtained by the improved evaluation method is 47.53%, and the damage degree is classified as medium to weak. Based on the result of the CIS evaluation method, the velocity sensitivity index is 23.25%, and the damage degree is classified as weak.

Considering the development of coal seam fractures and loose particle cementation, to avoid or reduce the impact of velocity sensitivity, the drainage velocity of the coal reservoir is generally small (generally less than 10 m^3/d). Therefore, the daily water production of the coal seam is calculated with a drill bit diameter of 139.7 mm and a reservoir thickness of 1.5 m, see (6). The feasibility of the improved method is verified by comparing the velocity-sensitive index measured by the two methods when the water yield is about 10 m^3/d.

$$Q_w = \pi v D h \qquad (6)$$

where; Q_w is the daily water flow, m^3·d^{-1}; D represents the diameter of the drill bit, mm; and h is the thickness of the coal seam, m.

The calculated results show that when the seepage velocity is 22.0 m/d, the water yield is 14.48 m^3/d, and the velocity sensitivity index measured by the CIS method and the improved method is 18.81% and 45.71%, respectively. When the seepage velocity is 14.7 m/d, the water yield is 9.66 m^3/d, and the velocity sensitivity index measured by the CIS method and the improved method is 15.78% and 33.42%, respectively. If the velocity-sensitive index of the two methods is 20%, the water yield corresponding to the CIS method is higher than 14.48 m^3/d, and the water yield corresponding to the improved method is lower than 9.66 m^3/d, which is highly consistent with the above conclusion, thus confirming the rationality of the

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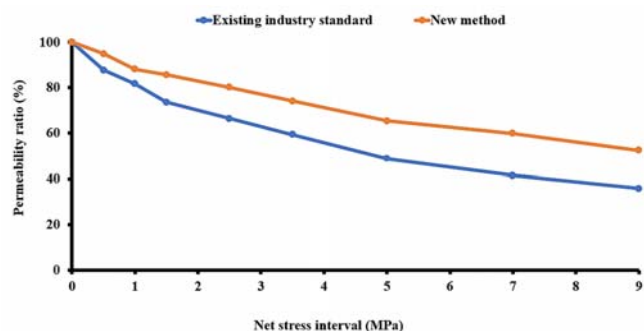Vol:16, No:5, 2022

improved method.

Fig. 2 Experimental results of stress sensitivity test curves by CIS and the proposed method

Comparing the results of the stress sensitivity experiment in Fig. 2, it can be seen that the stress sensitivity damage degree obtained by the improved evaluation method is lower than that of the CIS method, and the stress sensitivity index obtained by the improved evaluation method is 47.66%, and the damage degree is classified as medium to weak. Based on the result of the CIS evaluation method, the stress sensitivity index is 64.17%, and the damage degree is classified as medium to strong. The stress sensitivity index of the CIS method is 40.70% and 58.59% when the net stress changes between 3.5 MPa and 7 MPa, while the corresponding stress sensitivity index of the improved evaluation method is 25.88% and 40.15% respectively, which confirms the general understanding that the conventional evaluation method exaggerates the effect of stress sensitivity on coal seam, and thus verifies the rationality of the improved method.

V. Conclusions and Future Study

Through efforts, this study established an improved method for laboratory evaluation of sensitivity damage in CBM reservoirs via experimental and theoretical analysis. The recommendations of this study will be beneficial to future research and guide the development strategy for CBM reservoirs. The following conclusions are made;

1) The improved evaluation method overcomes the limitations of the conventional evaluation method, such as long test time, low data reliability, large gap with the actual situation, slippage effect, and so on. It is suitable for evaluating the seepage sensitivity of coal reservoirs characterized by permeability lower than 1×10^{-3} μm^2.

2) The exploitation of CBM generally goes through multiple-scale links of "desorption-diffusion seepage", and formation damage occurs throughout the whole development process. At present, the main focus is on the improvement of the seepage level method, which does not consider the influence of the desorption and diffusion of CBM on the seepage process. It is urgent to establish a CBM reservoir damage evaluation method that comprehensively considers the desorption performance, diffusion performance, and seepage performance.

3) The permeability of CBM reservoirs is relatively low, the

coal powder easily collapses (due to low cementation of the grains), and the formation water often leads to the blockage of the seepage channel. The initial test velocity and velocity interval setting of a coal seam velocity sensitivity evaluation experiment need to be further studied.

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